NOVEMBER, 1961

Welding Journal

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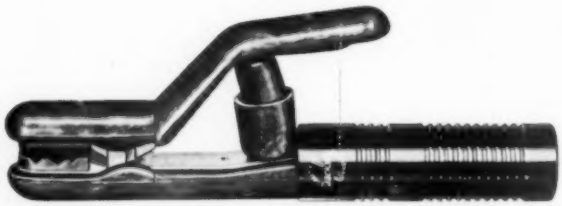
OFFICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY

cut welding fatigue with

Jackson Featherlight Holders



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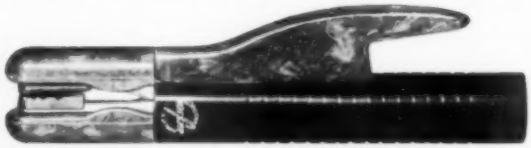

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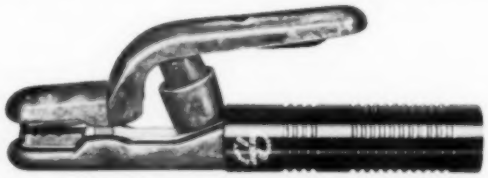

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Electrorama Demonstration

A three-day demonstration of the latest electric welding and cutting apparatus recently attracted 225 guests to an Electrorama held by Ohio Valley Sales Co., 709 Melish Ave., Cincinnati, Ohio.

Welding specialists from Linde Co., Div. of Union Carbide Corp., Metal and Thermit Co., Miller Electric Co., Rexarc, Inc. and Welsh Mfg. Co. aided Ohio Valley's sales staff by demonstrating the latest electric welding techniques and processes. Demonstrations of gas tungsten-arc welding and cutting also drew considerable interest from the shop managers and operators who attended.

Motzenbecker Appointed Sales Manager

George E. Motzenbecker has been appointed sales manager for Welding Gas & Equipment Co., distributor for Linde Co., Harnischfeger Corp., and other welding lines for the Detroit, Michigan area.

A native of New Jersey, Mr. Motzenbecker received a Bachelor of Science degree from Massachusetts Institute of Technology following army service in World War II.

Previous to his new appointment, he held sales and management assignments with the Linde Co.

George E. Motzenbecker

AMF Displays New Friction Welding Machine at Metal Show

The first public look at American Machine & Foundry Co. production unit friction welding machine took place at the National Metal Show, Oct. 23–27, Cobo Hall, in Detroit, Mich.

The production unit model 15-4 friction welding machine is the first of a new line which applies AMF's successful laboratory study and demonstration of the feasibility of friction welding.

The study of friction welding by the firm's research and development division proved that, for many types of welds, this method is more efficient than conventional methods and requires less power. It was also found that the new method generally eliminated the need for fluxes and special atmospheres.

Later in the year, using a prototype machine developed by the research and development division, friction welding was used—for the first time in the free world—to fill an industrial order for 1000 welds.

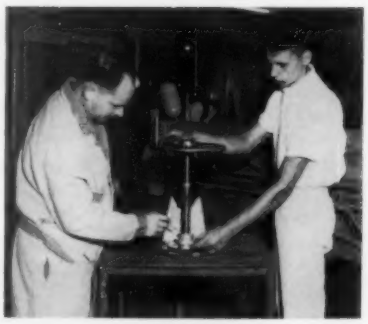
Space-Age Production Line

A new "push button" underwater explosive facility designed to form special parts for space craft is currently in operation at General Dynamics/Astronautics, San Diego, Calif. Astronautics plan to use this rapid, inexpensive process for producing intricate parts for missiles and space vehicles.

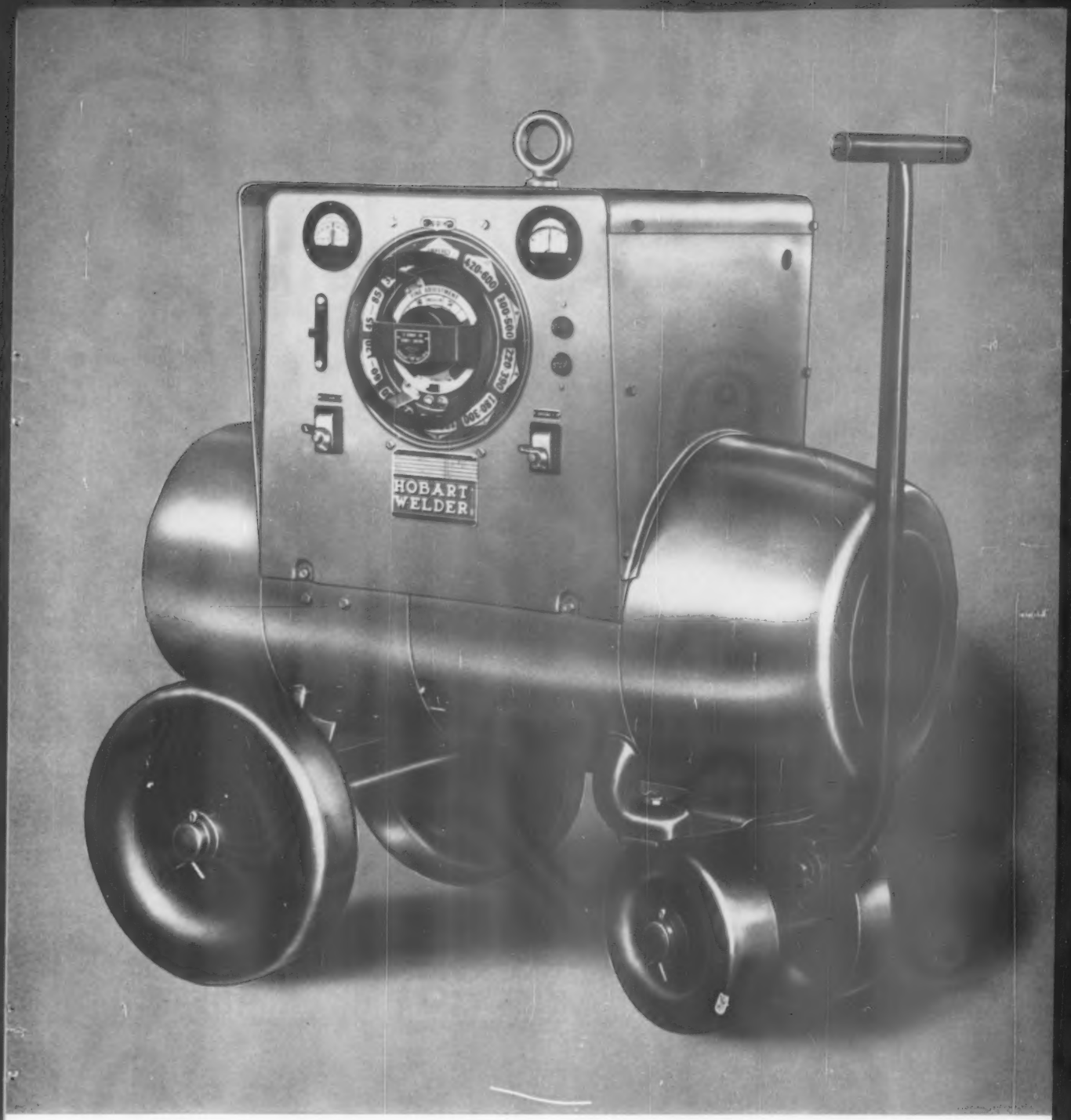
Flat or rolled metal plates formed are submerged in a 12-ft diam pool directly over a tool die in the bottom of the tank. Approximate half-ounce explosive "blasts" a sheet of metal with enough force to form a small missile part. Subsurface shock waves press the metal into the shape of the die within a split second.

The new hydro-chemical part forming technique will save time, materials and special and expensive tooling costs.

LINCOLN PRIZE WINNER



James Bright, Jr. (right) of Warren, Ohio, won $320 for his portable arbor press in the vocational trade and industry section of this year's $15,000 national high school welding competition sponsored annually by the James F. Lincoln Arc Welding Foundation. He is shown here with shop instructor, Michael Bushwack of the Warren G. Harding Memorial High School



Model MP-304-P

Best selling Hobart welder gets a NEW LOOK

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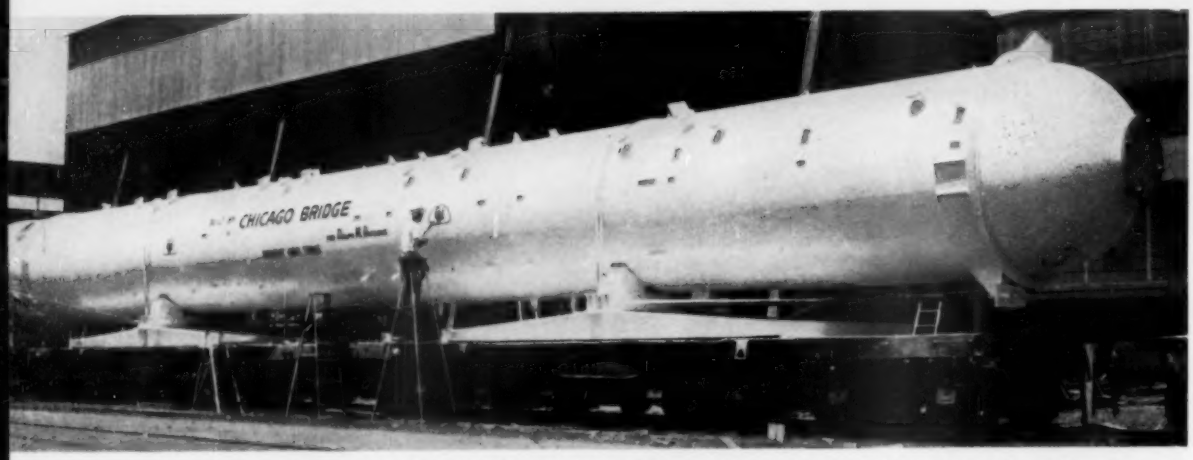
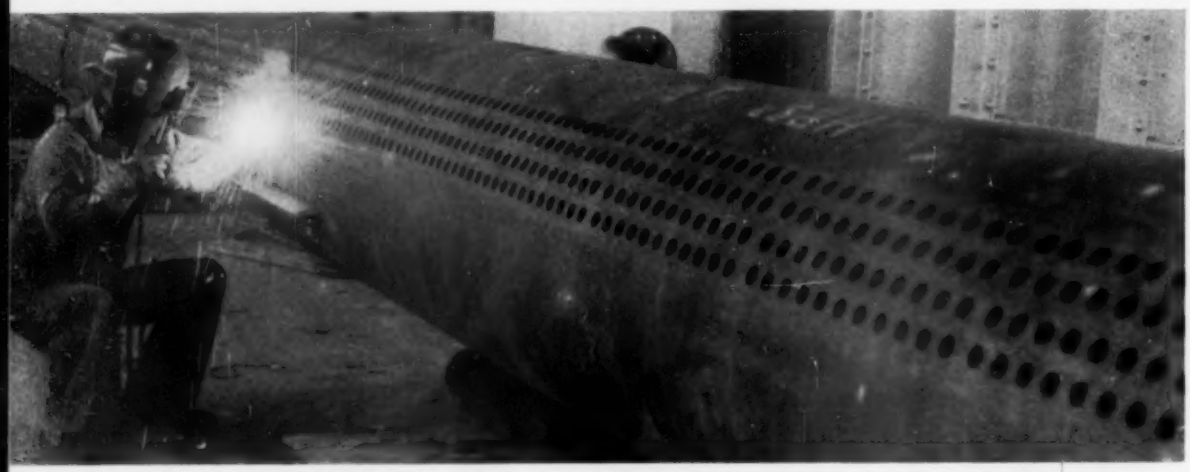
WELDING ZONES



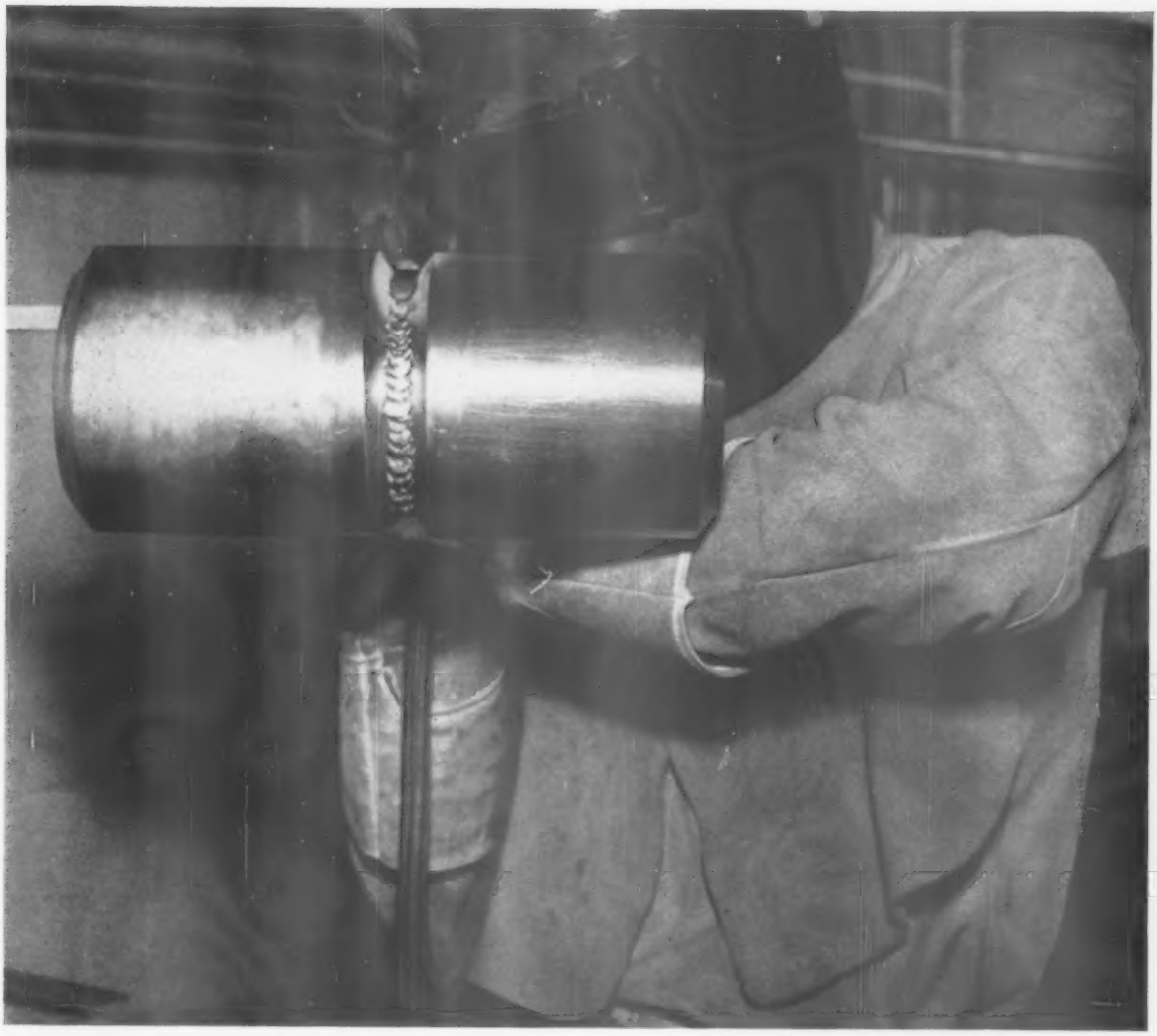
A giant iso-cracking refinery tower, fabricated of chrome-molybdenum steel plate, gets final touches before delivery to Ralph M. Parsons Co. for service at Standard Oil Co. of Ohio's Toledo refinery (Courtesy Chicago Bridge & Iron Co.)



Use of integrally finned tubing was designed and developed especially in heat transfer applications for a midwest electric plant (Courtesy Wolverine Tube Div., Calumet & Hecla, Inc.)

One of the largest all welded steel plate girders in the world is moved to a new mill at U. S. Steel's Gary, Ind., Steel Works (Courtesy American Bridge Div., U. S. Steel)

Welders complete fabrication of the stainless steel hangers within the patented chain section of a dry process kiln for a midwestern cement firm. (Courtesy Allis-Chalmers Manufacturing Co.)



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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

Austria

The May 1961 issue of *Schweisstechnik* contains a paper describing recent welded structures in Austria in the power plant and crane fields. Sketches show the weld design of a header for a Benson boiler and the box section used for the legs of a dock-side crane. Another article refers to a patented German process for deoxidizing fully austenitic stainless steels to prevent hot cracking during welding.

In the June 1961 issue, W. Hummitzsch refers to a fine grained steel containing 0.18 C, 1.0 Mn, 0.4 Si, 1.0 Ni, 0.9 Cu, 0.2 V with a minimum yield strength of 61,000 psi from which 120-ton capacity ship booms were fabricated by submerged-arc welding with Cu–Ni steel wire. Fine grain was achieved either by aluminum nitride or by Mo, V, or Cb carbide. Another article illustrates automatic welding machines for spiral joint pipe and for surfacing valve housing with the bronze by metal-inert-gas welding. A machine for following curved seams in submerged arc welding also is described.

Belgium

Research work by the Corniglio firm of Italy on welding galvanized steel is reported in the June 1961 issue of *Acier-Stahl-Steel*. The welds were made in 0.050 in. thick Sendzimir continuous hot dip sheet 0.05 in. thick with 0.97 oz of zinc/sq ft. Bronze welds were not as strong as arc welds made with covered electrodes. Both required protective coating to prevent rust, sprayed zinc being most effective. Zinc-base paint with a cover coat of alkyd resin paint also was recommended for salt spray corrosion resistance.

France

The May-June 1961 issue of *Soudage Et Techniques Conneyes* contains the following articles:

• A discussion of proposed French standards for covered electrodes which are based on a specification by the International Standards Organization already adopted by West Germany, places greatest emphasis on interpass pass-temperature and hydrogen content. The specified interpass temperature of 480° F is said to raise the strength and lower the elongation 5% compared with the present French standard. The proposed hydrogen content of 5 cc per 100 gm maximum is not the best possible form of specification. A specification based on a test for the effect of hydrogen rather than on its quantity seems preferable.

• A paper on spot welding in the automotive industry shows several large spot welding units for Citroen, Renault and Peugeot chassis. A completely automatic butt welding unit produces 1200 spark plug electrodes an hr. Machines converting three phase to low-frequency single phase are shown to be desirable only when low power factor due to long hours must be overcome. The trend in spot welding electrodes is toward a spherical tip, $3^1/_4$-in. radius with $^1/_8$-in. radius at the corners.

• Several fatigue failures in welded locomotives, trucks and ships are analyzed.

• Several systems of lowering the open circuit voltage of arc welding power supplies to 40 v during idle periods are compared.

• A new specimen for studying the capillary rise of brazing material in vacuum consists of a stainless steel cylinder pressed against one side of a hole 0.02-in. larger in diameter. Radiography reveals the extent to which the brazing material flows up the side of the hole. The clearance is zero where the bar is in contact with the hole, and 0.02-in. at 180 deg. A nickel alloy containing 7 Cr, 9 Si, 17 Mn, 1.8 B penetrated well, but formed hard intermetallic phases.

• A long review of aluminum welding by an engineer of the French Institute of Welding states that butt welds in unalloyed aluminum for the chemical industry are peened and annealed. The two-operator vertical method of oxyacetylene welding is recommended to avoid crater cracks and tungsten inclusions. For Al-Mg alloys argon arc welding is necessary. Crack tests for these alloys are discussed at length.

East Germany

Zis Mitteilungen for June 1961 contains the following articles:

• The cooling rate of a root pass of a low hydrogen electrode in a butt weld was measured for plates $^3/_8$ to 2-in. thick, for preheats up to 750° F, and for electrodes $^1/_8$-to $^1/_4$-in. diam. Cooling rates were expressed as seconds to cool from 1560 to 930° F. The logarithm of cooling time was inversely proportional to plate thickness. The results were applied to TTT curves for several alloy steels to avoid martensite in welds.

• The application of the Schaeffler diagram to welding with austenitic filler metal is explained.

• The problems in welding clad steel are discussed.

• The suitability of rimmed steel for welding with covered electrodes and submerged arc has been established. East German designers are urged to substitute rimmed for killed steel up to $^5/_8$-in. thick wherever possible.

• Spectrum line photometry showed that the temperature of the arc for a bare steel electrode $^1/_8$-to $^3/_{16}$-diam in air at 115 to 280 amp was 6000° K. Common types of covered electrodes were 200 to 600 deg lower.

• The Impalla process of welding copper to aluminum electrical conductors consists in interposing a piece of silver between the two metals. The silver is welded first to the copper, then to the aluminum, both welds being made by the resistance butt process.

The July 1961 issue of this publication contains several papers on aluminum welding. The first paper provides diagrams of permissible stress in fatigue for 5% magnesium alloy. In pulsation stress the permissible value varies from 2800 to 9500 psi, for fillet and butt welds, respectively.

Another paper reports that the tensile strength of welds in 1.1 Mg, 4.7 Zn, 0.5 Si, 0.43 Fe, 0.55 Cr alloy rises during aging at room temperature from 30,000 psi immediately after welding to 43,000 psi after 90 days. Since the strength of the unwelded alloy is 50,000 psi, this alloy is regarded as the only aluminum alloy that is not seriously softened

DR. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

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Above: A valve, with its ends protected by masks, receives a sprayed overlay of Colmonoy No. 6 hard-surfacing alloy. Left: A finished valve with long-wearing Colmonoy alloy stem surface.

Colmonoy Spraywelder Builds Longer Life into Aircraft Valve

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Besides being an ideal method of applying a hard surface to finished machined parts, the Spraywelder employs the finest of hard-surfacing materials: Colmonoy nickel-base alloys. There are now eight Colmonoy alloys available as Sprayweld* Powders.

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by welding. Precipitation of $Al_2Mg_3Zn_3$ was detected in the weld metal. A similar alloy called Hegal, patented in Hungary, was used to construct prototypes of welded bridges and track bodies which behaved well in static and fatigue tests.

The principle of the Impalla process was used to weld copper conductors to aluminum arms in electrolytic cells. The silver was applied by the tungsten arc process.

It was found that insertion of a 40,000 microfarad condenser enables a steady arc to be maintained in gas tungsten-arc welding aluminum without HF. The arc became so sensitive to changes in length during welding that this method of sidestepping HF was not generally practicable.

Holland

The July 1961 issue of *Lastechniek* contains three articles on pressure vessels. The first describes the organization of manufacturers and users of boilers and pressure vessels in Holland. Charts show the division of the main Bureau into a general technical service and a scientific department with mechanical and chemical laboratory and facilities for stress analysis. In 1959 there were 23,214 pressure vessels in Holland, of which 11,352 were boilers. The second article on submerged-arc welding of pressure vessels warns against pear-shaped bead cross sections with attendant centerline cracks. An included angle of 60 to 90 deg is recommended for butt joints in plates $^1/_2$-to $1^1/_4$-in. thick, and 15 deg for deep grooves in plates over $1^1/_4$-in. Graphs show the relation between MnO and SiO_2 content of flux and the manganese and silicon content of the weld. The third paper illustrates the relation between ultrasonic echoes and weld defects, and describes a scale for insertion in the defectoscope screen to facilitate determining depth of defect.

Italy

The May-June 1961 issue of the Italian Welding Society magazine contains the first part of a theoretical paper on brittle fracture by A. Nacher, Director of the Inspection Laboratory of the Italian military. The Mohr-von Mises approach is taken to elastic fracture, but fracture after plastic deformation is discussed in qualitative terms with review of experimental work on notch specimens.

• Also in this issue is a report on radiography of fillet welds. Compensation for the variations in thickness to be penetrated is made by inserting an absorbing wedge at the tube. The thickest side of the wedge intercepts the ray passing through the thinnest part of the fillet assembly.

Switzerland

The welding paper accorded first prize at the 50th Anniversary meeting of the Swiss Welding Society is printed in its magazine for June 1961. The paper describes the welding of 13% Cr steel castings, which are particularly suited for hydroelectric turbines. Tests were made on 2-in. sq castings containing 0.07 C, 0.44 Mn, 0.43 Si, 12.32 Cr, 0.89 Ni. Weld metal from lime-base electrodes had essentially the same composition. Three precautions were essential. First, preheat to 390–750° F, preferably the latter to avoid cracks. Preheating to 1110° F would be desirable, were it not for the low notch impact value of the weld. Second, the weld should be reheated 12 hr at 1260° F and cooled in air to relieve stresses, if the weld is in a highly stressed region or is of considerable extent. Third, undercut should be carefully removed by machining in order to secure a notch fatigue strength (10 million cycles, notch radius = 0.005 in.) of 20,000 to 24,000 psi, equal to base metal. The unnotched fatigue strength of the weld was equal to base metal, 42,000 psi.

West Germany

Schweissen und Schneiden for June 1961 contains the following articles:

• A four-number system has been established for classifying the quality of flame cut surfaces. The four numbers refer to measurements of drag, planeness of cut surface, depth of drag lines, and radius of upper edge. The highest quality cut is designated 1111, whereas the lowest quality is 5555.

• Twenty-one commercial electrode holders were subjected to tests for mechanical strength, grip strength and pressure, electrical insulation, heat resistance, and moisture resistance. Desirable specification values for test results are given. In many of the tests the holders were uniformly satisfactory, but in some, the contact pressure test, for example, results varied widely from holder to holder.

• The construction and application of welding positioners are discussed.

• Twenty-four standard designs of welded supports for boilers are illustrated.

• German Standard DIN 8555 for hard surfacing filler metals has been issued. Seventeen standard compositions are given, and there are seven hardness steps from 125 to 530 Brinell or from 37 to over 68C Rockwell. Ten of the compositions are iron-chromium base with up to 5% carbon. Three are copper-base, the remaining four being stellite, tungsten carbide, and high-nickel alloys.

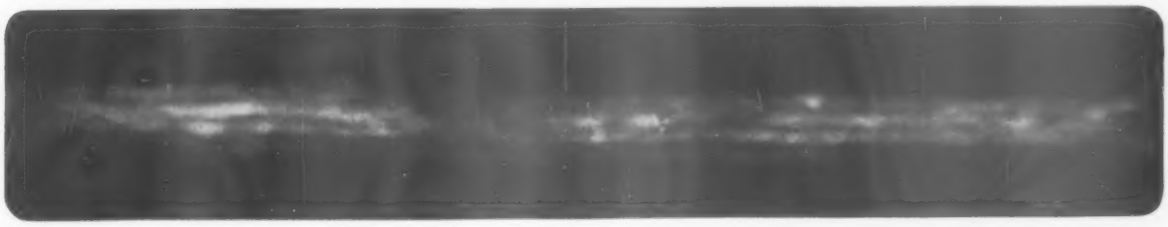
WEST GERMANY

Welding of a boiler at the Henschel-Werke G.M.B.H. in Kassel, Designers and manufacturers of steam generators

For "X" months under the sea—

every weld must be sound

By use of radiography defective welds are detected ar.d corrective measures can then be taken.



To make sure, Electric Boat, division of General Dynamics Corporation, checks every weld by radiography, using Kodak Industrial X-ray Film, Type AA.

The welded hulls of today's nuclear subs contain a maze of intricate piping, machinery, controls and equipment—much of it welded. Radiography of these welds has helped Electric Boat of Groton, Conn., pile up phenomenal records of dependable performance.

At Electric Boat, every weld that radiography shows to be less than perfect is repaired or replaced. It is the only way to be sure that superb performance will not be marred by a "weak link."

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Square deal?

HARNISCHFEGER

Milwaukee 46, Wisconsin

P&H WELDING PRODUCTS DIVISION

An AWS Task Force

The use of welding techniques has been accepted as the major art in the fabrication of simple as well as complicated structures. Rules and specifications for operational procedures, nondestructive tests, and qualification tests for personnel performing these functions became necessary.

The application of the art spread rapidly into many fields. Numerous governmental agencies, industrial groups, and engineering organizations prepared rules and specifications governing the procedures as they affected various end products. This has resulted in many overlapping and conflicting rules and procedures covering almost identical details of application.

Today it is often confusing and costly for fabricators to determine what rules or specifications govern the fabrication of structures designed to accomplish the same end functions. Numerous codes covering certain fields of application have been written and accepted, but much remains to be done to accomplish greater uniformity and standardization.

Serious consideration should be given to the appointment of a "task force" to study this complex problem and recommend solutions. It should be sponsored by the AMERICAN WELDING SOCIETY and supported by the Engineering Foundation. It should work with the Engineering Societies' Code Committees, the Department of Defense and other governmental agencies.

Certainly a greater degree of uniformity in nondestructive testing and welder qualification testing can be accomplished. The daily introduction of new techniques and processes, new materials and more complicated structures highlight the need for such an effort.

The consolidation of diverse rules and procedures has been accomplished successfully in many other fields.

A similar consolidation in the field of welding would be a significant step toward a stronger and more effective national effort.

L. S. Wilcoxson

Vice-President
Babcock & Wilcox Co.

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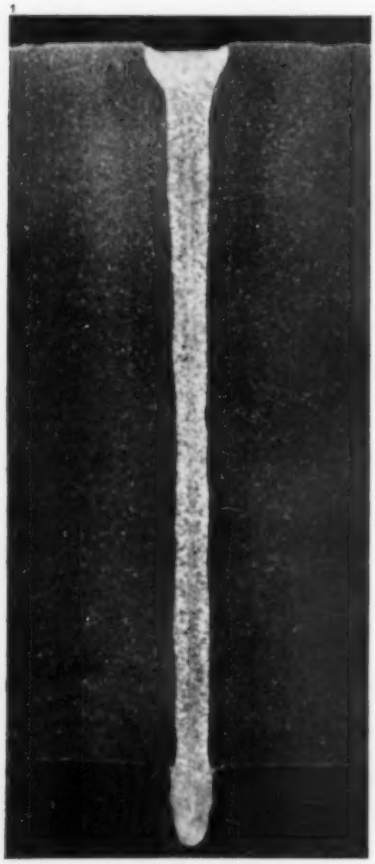

1 / Penetration study of one-inch thick Type 302 stainless steel reveals an amazing depth-to-width ratio. High-energy density and sharp focusing produce this unique weld with no reduction in the original strength of the material.

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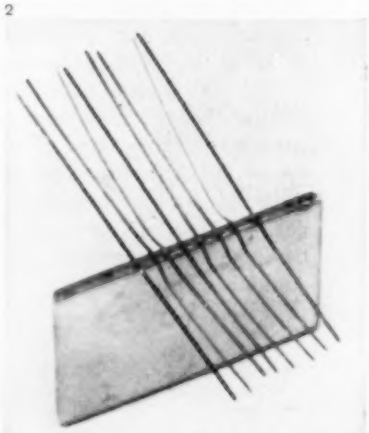

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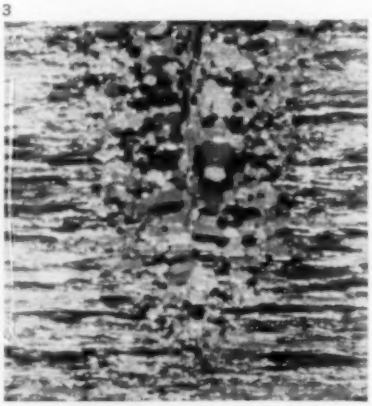

3 / Study of weld on 0.100" tungsten shows minimum grain growth and no evidence of contamination. The high-energy density beam minimizes grain growth because welding time is extremely short and heat is applied to an exceptionally small zone. Contaminants are eliminated by welding in a high vacuum without filler; impurities are outgassed during the cycle.

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Whiting Refinery's 140,000 barrel per day crude unit

Welding Keeps **Oil Refinery** Mechanical Equipment Operating

through the repair of shafts, switch cocks, gate valves and pumps, using both gas and arc processes

BY RAY M. KOLB

The outward appearance of an oil refinery reveals many welding applications. One can see welded piping, welded tanks, welded pressure vessels, and welded structures. These apparent applications are vital to modern oil refinery operation. It is the purpose of this paper, however, to discuss some of the less apparent uses of welding in refining—those related to the repair of mechanical equipment such as pumps, compressors, turbines, electric motors, fans and valves.

Constant improvements in welding equipment and materials have permitted hundreds of repairs that would not have been attempted even ten years ago. Economy in refinery operation has led to a policy of stocking a minimum of spare parts. Frequently, welding is used to repair parts not carried in inventory. Successful repair permits the return to operation of equipment that might otherwise be waiting for a new part from the manufacturer. Experience has indicated that in most cases the welded repair is cheaper than a new part; often by using a harder or more corrosion-resistant welding material the repaired part will outwear a new one.

Machinists have accepted welding as a necessary process in the maintenance of refinery mechanical equipment. Their cooperation with welding personnel has been a major factor in the success of many jobs.

The following is intended to describe some of the typical welding applications successfully used on mechanical equipment at the Whiting Refinery of the American Oil Co.

Repair of Induced Draft Fan Shaft

The Whiting Refinery generates its own electric power. This presented the challenging problem of repairing five badly corroded induced draft fan shafts. Figure 1 shows the damaged area on one

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Paper presented at the AWS National Fall Meeting held in Dallas, Tex., during Sept. 25–28, 1961.

Fig. 1—Corrosion of induced draft fan shaft

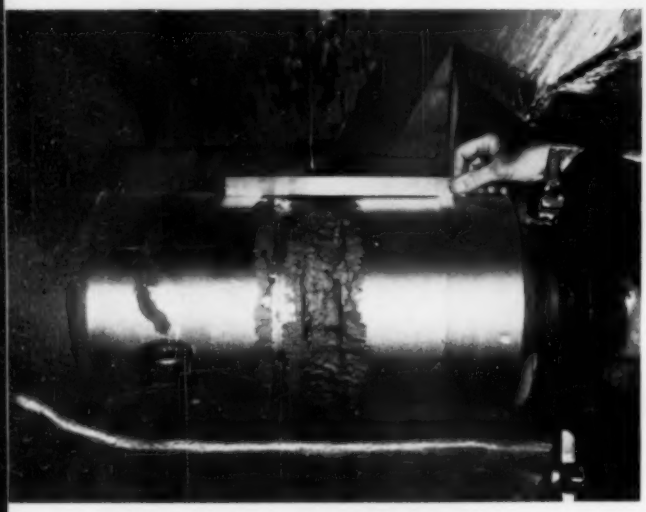

Fig. 2—Setup for machining out the corroded areas

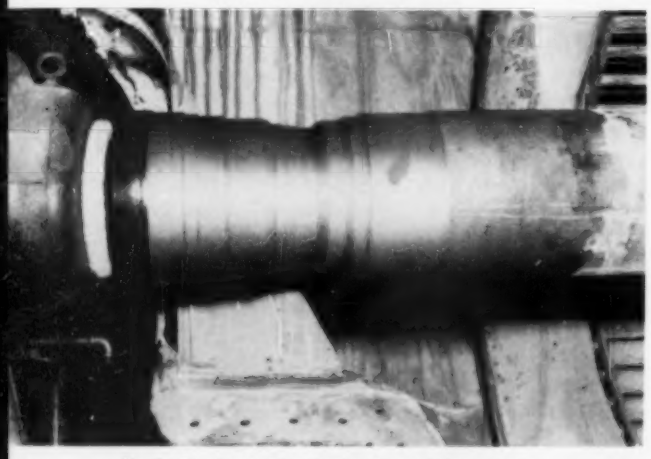

Fig. 3—Shaft machined out and ready for welding

of the 12-in. diam by 30-ft long shafts. There were two corroded areas on each shaft. The deterioration is known as "dew-point" corrosion. It is caused by the water-cooled bearings on each end of the fan chilling the shaft sufficiently inside the fan housing to permit condensation to occur. The flue gas coming in contact with the condensed water resulted

Fig. 4—Submerged-arc welding setup for fan shaft

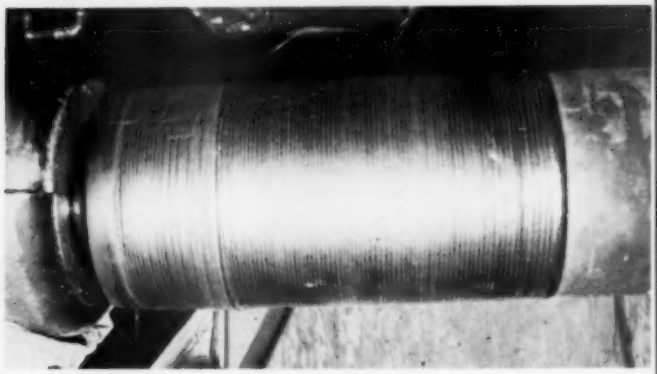

Fig. 5—As-welded appearance of the shaft

in the formation of acid and, consequently, the corrosion. The SAE 1035 steel shafts were damaged in areas up to 2 ft in length and to a depth as great as 2 in.

While it would normally be desired to do jobs like this in the shop, there were several major factors that influenced a try to repair the shaft in place. First, the fans are located on the sixth floor of the power station and movement of these heavy rotors to the shop would have been costly and difficult. Second, it would have been necessary to remove the impeller from each shaft in order to machine out the corroded areas. The impellers are constructed with cast-iron hubs and are pressed onto the shafts. It was feared that these hubs would be so tightly corroded to the shafts that, in trying to remove them, the cast iron might break. Third, a cost analysis indicated that a field repair would be far less costly.

Before any welding could be done, the deteriorated areas had to be machined out. Figure 2 shows how a star feed facing device from one of the shop boring mills was mounted next to the fan shaft. Rotation was accomplished by an air motor mounted to rotate the entire fan assembly at about 10 rpm. Longitudinal movement of the cutting tool was accomplished by the bar, shown tack welded to the shaft in Fig. 2, moving the star wheel one tooth for

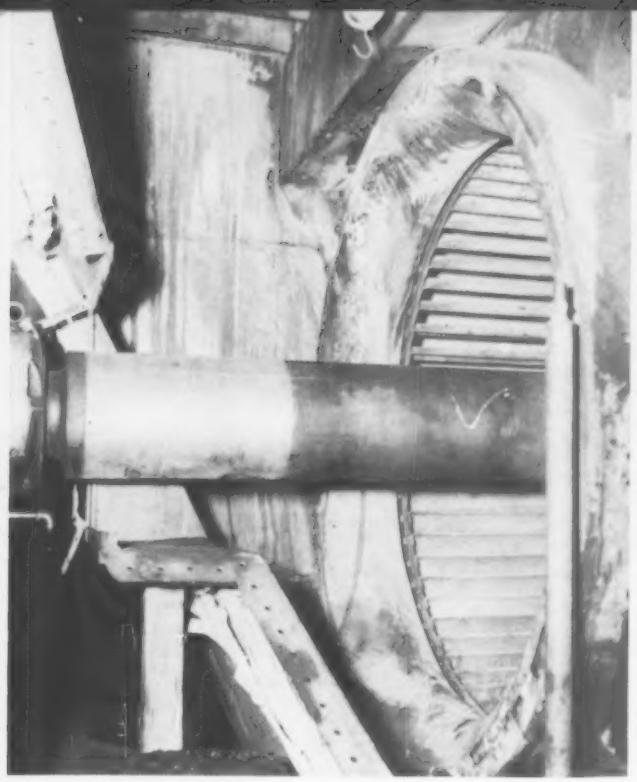

Fig. 6—Shaft after finish machining

Fig. 7—Switch cock plug welded by the submerged-arc process

every revolution of the shaft. Rotation of the star wheel causes movement of the cutting tool through a feed-screw arrangement. The depth of cut was set by tapping the cutting tool lightly with a hammer. Figure 3 shows one of the areas machined out and ready for welding. One of the main reasons for accurately machining the shaft prior to welding was to provide for uniform weld metal deposition around the shaft to minimize the possibility of distortion.

Automatic submerged-arc welding was chosen to do the job. Figure 4 shows the rig for holding the welding nozzle and moving it longitudinally through a rack and gear arrangement. With each revolution of the shaft, the operator would move the nozzle over far enough to permit deposition of an adjacent weld bead. A tank large enough to hold an adequate supply of flux for the entire job was mounted overhead. The hose from the flux tank to the welding cone is visible in Fig. 4. A valve in the flux line permitted the operator to fill the cone whenever the supply ran low. Surplus and fused flux was collected in a tray below the shaft and later screened to permit use of the unfused portion. Because of the lower speed required for welding, a variable speed face plate type positioner was taken to the job and hooked-up to rotate the fan shaft through a double universal joint.

Prior to welding, the shaft was preheated to 400° F with the shaft rotating. Welding was accomplished at 350 amp and 30 v with a travel speed of 25 ipm. Mild steel wire, $^{3}/_{32}$ in. in diameter, was used. As a precaution against distortion, rotation of the shaft was not interrupted through preheating, welding and cooling to room temperature.

Figure 5 shows the as-welded appearance of the shaft. The amount of weld metal required to make this repair varied from 60 lb on the least damaged area to 140 lb on the most severely damaged one. Figure 6 shows the completed repair after finish machining. The machining setup shown in Fig. 2 and previously described was used for finish machining. All the shafts were checked after welding, and the degree of bending or distortion was negligible.

Repair of Coking Drum Switch Cocks

In the delayed coking process, hot reduced crude oil at about 900° F is fed into a large "coke drum" which eventually fills with coke. When it is full, the charge is diverted to another coke drum while coke is removed from the first one. The valves used to control this flow are heavy-duty plug cocks referred to as switch cocks. In service they must hold the 900° F oil at about 35 psi, resist the abrasive action of coke, and withstand temperature cycles once every two days from the 900° F oil temperature to that of cooling water which may range from 40 to 70° F depending on the season of the year.

These cocks consist of a tapered plug made of Type 410 stainless steel, which is precision machined to fit into a corresponding tapered seat in the Type 502 stainless steel valve body. Rotation of the plug within the body regulates the flow. This rotation eventually results in wear and leakage making it necessary to recondition the switch cock. Repair is accomplished by remachining, grinding and lapping together the tapered surfaces on the plug and the body. After this is done a few times, the plug drops down too far into the body and corrective action must be taken.

One way to solve the problem is to purchase an oversize plug and fit it to the enlarged tapered bore in the body. After continued reconditioning, a point is reached where no further reboring of the body can be tolerated because of minimum wall thickness requirements. A solution would be to purchase a new valve body to standard dimensions

Fig. 8—Switch cock plug being machined after welding

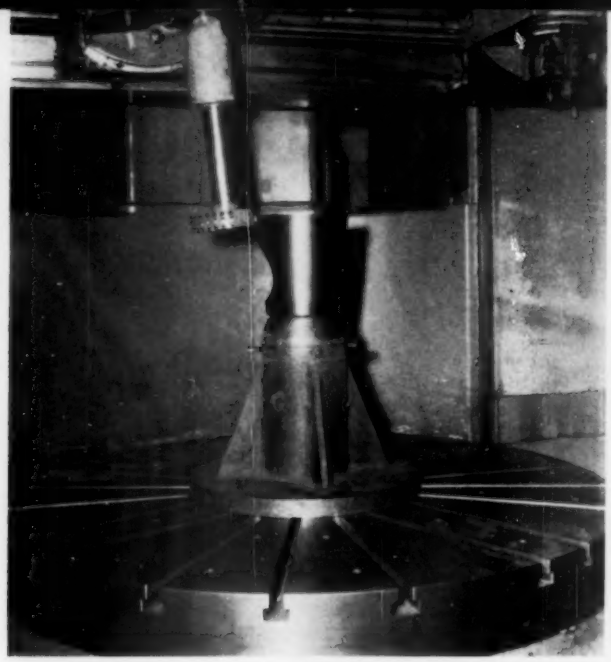

Fig. 9—Grinding attachment finishing switch cock plug

and machine a plug to fit it. However, it has been found that repairing both the plug and the body by welding is more economical and gives a harder, better wearing surface.

The setup for welding the plug by the automatic submerged-arc process is shown in Fig. 7. In order to keep welding continuous once it has started, formed plates are welded into the port openings. Starting and run-off pads are used to assure welding the entire plug surface.

The welding procedure calls for a 400° F preheat, $^{3}/_{32}$ in. Type 410 stainless steel filler wire, 350–400 amp, 28–30 v and a travel speed of 15 ipm. Welding is done circumferentially; after each revolution, the welding head is stepped over the width of a weld bead by means of a worm and wheel drive without breaking the arc. Upon completion of welding, the plug is allowed to air cool. After cooling, the plug is tempered at 950° F before machining.

Figure 8 shows a plug being machined on a vertical boring mill following welding. The boring ram is set at the proper angle and the plug is turned to within 0.060 in. of finished diameter. An electric motor driven grinder has been adapted to fit the boring ram, and Fig. 9 shows it finishing a plug to size. The plates used to permit continuous welding have been removed in this picture; however, it has been found better to leave them in until after grinding is complete. The open ports cause an interrupted grinding cut which results in reduced grinding wheel life and dimensional inaccuracies.

To obtain a tight fit, the tapers of the plug and the body must match exactly. This is accomplished by machining and grinding both the plug and the body with the same angular setting of the boring ram. Figure 10 shows a body in place under the grinding wheel. A centering plug attached to the boring mill table is used to center the body. Retaining jaws not shown in this photograph are used to hold the body during machining.

While the body is rebored during every reconditioning operation, it is welded internally rather infrequently. As previously mentioned, the fit is normally restored by building up the plug. This is preferred because it is easier to weld the outside of the plug than the inside of the body and, also, because the body requires a more extensive heat treating operation.

Internally welding the tapered bore in the bodies is done by the automatic submerged-arc process with the rig shown in Fig. 11. The welding head is tilted so that the wire feeds out horizontally. A specially designed extention nozzle fabricated from pipe with a 90-deg bend at the end carries the wire inside the bore and directs it against the bottom surface. The nozzle has been electrically insulated on the outside, since it is charged from contact with the filler wire.

A conventional face plate type positioner, shown in Fig. 12, is used to affect rotation. It should be noted that the face plate is tilted so that the bottom of the bore, where welding is taking place, is horizontal. The formed plates fitted into the ports to permit welding are visible in the photograph. Flux is fed in as needed from an overhead hopper. Circumferential weld beads are deposited side by side, by backing out the nozzle the width of a weld bead after each revolution of the body. This movement is accomplished by turning the handwheel just behind the operator and above the control box in Fig. 12.

The welding procedure calls for a 400° F preheat, $^{5}/_{32}$-in. Type 502 stainless steel filler wire, 350–400 amp, 28–30 v and a travel speed of 15 ipm. After welding, the bodies are heat treated by heating them to 1350° F at a rate of 200° F per hour, holding for

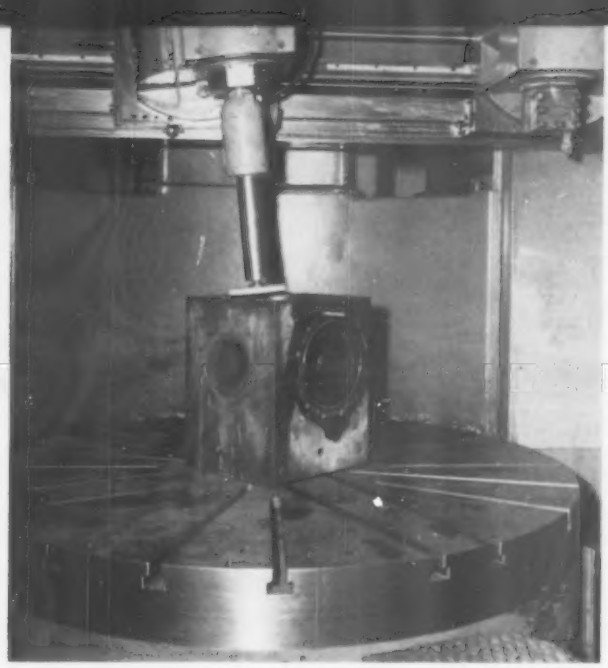

Fig. 10—Grinding setup for switch cock bodies

Fig. 11—End view of switch cock body being welded internally

4 hr, cooling to 600° F at a rate of 200° F per hour, and furnace cooling. After heat treating, they are machined by turning the bore to within 0.060 in. of finished diameter and then grinding to size.

It is specified that the minimum body hardness be 150 Brinell and that the plug be at least 50 points harder. Following the heat treating procedures given above, a body hardness of 200–250 Brinell and a plug hardness of 325 to 375 Brinell are being attained.

Gate Valve Repair

There are thousands of gate valves within a refinery. They consist of a wedge shaped gate, which is forced in between renewable seat rings that are usually screwed into the body. The forcing action is generated through a threaded valve stem. Welding plays a major role in reconditioning all of these gate valve parts.

For a valve to hold, it is essential that the sealing faces on the gate and the seat rings be flat and seal all the way around. In many cases, the repair to a valve consists of no more than machining, grinding or lapping these surfaces flat. However, whenever metal is removed from either the gate or the seat rings, the gate must drop down deeper into the valve to make a seal. Eventually, depending upon the severity of wear and the number of times a valve has been reconditioned, the gate will drop too far into the valve to make a seal. When this occurs, either new seats and a new gate must be installed or the gate can be made thicker by welding up the sealing surfaces on both sides of it. Figure 13 shows a valve gate that has been welded in this manner. This particular valve gate was restored with a chrome-nickel-boron, hard-facing alloy applied by oxyacetylene welding. A preheat of 800° F was used, and it was allowed to cool very slowly after welding by

Fig. 12—Side view of switch cock body being welded internally

Fig. 13—Valve gate built up by welding

Fig. 14—Valve gate being ground after welding

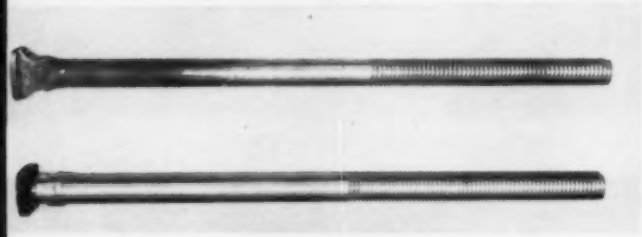

Fig. 15—Comparison of an old valve stem with a reclaimed one

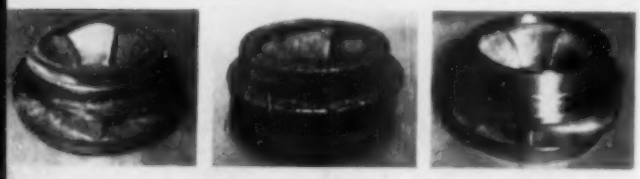

Fig. 16—Repair of worn pump impeller

placing it in ground asbestos. Type 410 stainless steel is a favorite valve gate material and covered Type 309 stainless steel electrodes are used to build up the sealing surfaces when they are worn. There are also numerous carbon steel and Type 304 stainless steel gates which are restored by manual electric welding using electrodes of matching composition.

Figure 14 shows a valve gate being ground to size on a vertical surface grinder. It is mounted on an adjustable angle fixture which is set to hold the surface to be ground in a horizontal position for grinding. When both sides of the valve gate are hard faced, the disk is supported on the guide slots in the side of the gate until the first face has been ground. It is then turned over and supported on the finished surface while the second one is ground. The machinist usually has the valve body next to him and fits the valve gate into the body by trial. However, in the case of valves welded directly into piping it is necessary to work to dimensions taken on the job site.

Valve stems can cause repair problems. Essentially, a valve stem consists of a "tee" section for attachment to the valve gate, a threaded area through which force is impressed to seat the valve, and the straight round length against which the

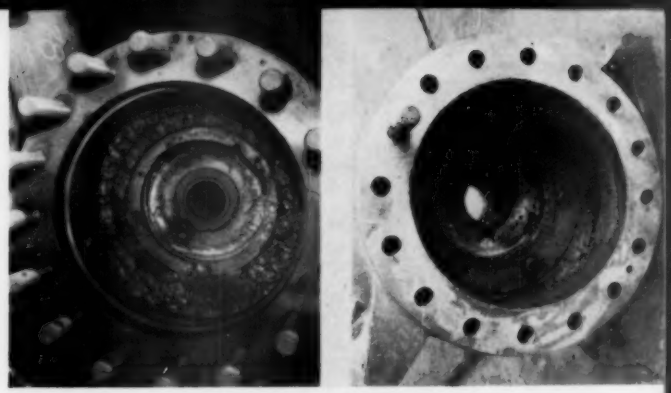

Fig. 17—Eroded pump casing before and after repair

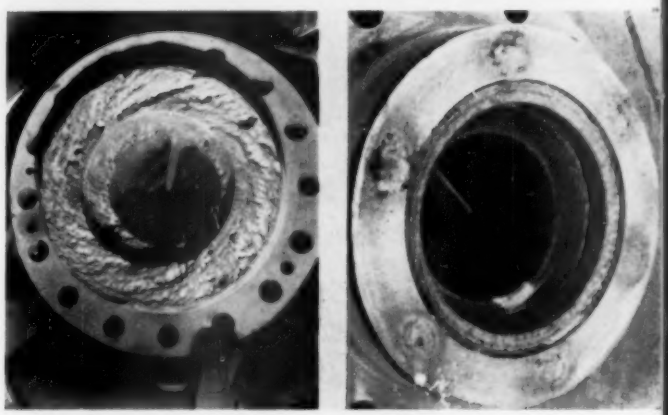

Fig. 18—Eroded pump head before and after repair

packing rides to affect a seal. Wear in the packing area can readily be repaired by metallizing. However, there are cases where the valve stem is badly bent or the screw threads severely damaged and repair is more difficult.

It is effective to fabricate a new valve stem from bar stock utilizing the old tee section which would otherwise be difficult to form. Figure 15 shows an old valve stem requiring replacement compared with one of a slightly different design that has been fabricated using the old tee section. The repair is accomplished by cutting the old valve stem off about 2 in. away from where it tapers back to the normal diameter. This 2-in. length is then turned down to about one-fourth of its original diameter. A corresponding hole is then bored into a suitable length of bar stock to serve as a pilot for centering the tee section. The abutting surfaces are then beveled with a 60-deg U-type joint and joined with a circumferential weld. After cutting the threads and finish machining, the valve stem is ready for service. The weld is made with Type 309 stainless steel if the valve stem is made of Type 410 stainless steel or SAE 4140 which are favorite materials for this service.

Pump Repair

Liquids are moved through an oil refinery by

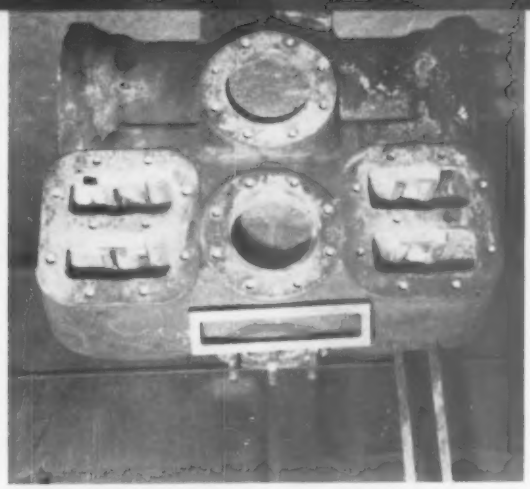

Fig. 19—Pump body with welded-in valve seats

Fig. 20—Use of the gas metal-arc process to install valve seats

pumps. Many different sizes and styles of pumps are needed to move the multitude of different fluids encountered at greatly different temperature and pressure conditions. Centrifugal pumps are by far the most widely used, but there are still applications where reciprocating or positive displacement pumps are preferred. Regardless of the kind of pump, welding is frequently called upon to keep them in operation. The following examples are typical of the many pump maintenance applications.

Figure 16 shows a badly worn centrifugal pump impeller, how it looked after welding and its appearance following machining. This impeller is made of Type 304 stainless steel and became damaged after a thrust bearing failure allowed it to rub against the pump casing. There was no spare impeller, and the manufacturer needed four to six weeks to supply a new one. Because the pump was urgently needed, there was no alternative but to weld it. The repair was made by manual arc welding using a $^{3}/_{32}$-in. Type 308 stainless steel electrode. The outer surfaces were readily machined in a lathe but hand grinding was required to finish the vanes. Following the machining operations, the impeller was dynamically balanced and the pump was returned to service.

Abrasive materials in the stock being pumped can result in severe wear and create difficult repair problems. Figure 17 shows a badly eroded pump casing before and after a welding repair. The pump is used on a fluid catalytic cracking unit and takes suction off the bottom of a distillation tower. It pumps a slurry of hot oil (700° F) and silica-alumina catalyst. The amount of catalyst in the slurry depends upon the condition of the separating system and increases with wear in the unit. While the catalyst is fine, about like talcum powder, it results in considerable pump erosion, especially when the concentration is high. Figure 18 is a before-and-after view of the pump head which suffered erosion similar to the casing.

Repair of these eroded parts was accomplished by machining out the damaged metal and restoring it with weld metal. To fortify the pumps against future erosion, wear plates of a chrome-nickel-boron alloy were fitted into the casing and head. The plates were attached by countersunk cap screws which were then welded over with a similar alloy. Hard surfacing could have been applied directly to the pump casing instead of using the hard wear plate. It was feared, however, that the relief cracking, common in hard surfacing, might progress into the base material and to play safe the hard wear plate was used. Originally these pump casings and heads were made of Type 410 stainless steel. When it was found that extensive repair welding would be required to maintain them, new casings of carbon steel were purchased so that the preheat and post-heat for welding could be eliminated.

Figure 19 shows a silicon bronze reciprocating pump body. Originally the block valve seats were an integral part of the casting. As they hammered flat in service, a welding repair became necessary. Ten years back, the procedure was to preheat the entire casting and build-up the seats by acetylene welding. It was a difficult and uncomfortable job to reach in through the small rectangular access holes and weld under a 600–800° F preheat. A method was developed at that time to machine the valve seat area flat and attach a precast and machined valve seat by means of a fillet weld. One of these seats is lying on top of the pump in Fig. 19. The fillet weld was made manually, using covered bronze electrodes. Figure 20 shows how these fillet welds are made today, using the gas metal-arc process. To gain accessibility, an extension had to be designed and installed on the welding gun. One of these pumps was repaired using cast Hastelloy (Alloy B) valve seats attached to the pump by furnace brazing. A silver-base brazing alloy (AWS/ASTM Specification B260-56T, alloy BAg-3) in foil form, 0.015 in. thick, was placed between the mating surfaces and the seats were clamped in position. Furnace brazing was then accomplished at 1410° F. If this trial installation proves satisfactory, this may become a standard repair procedure in the future.

Spot-welding machine for cargo container

Fig. 1—Metal desk standard

A variety of applications combined with new developments, which include space welding, are evidence of the growing usefulness of

Gas Metal-Arc **Spot Welding** in Industry

BY R. P. SULLIVAN

Since its introduction in 1955, gas metal-arc spot welding has become widely used as a fabrication tool on most of the common metals. Each day uncovers new applications for this versatile process. Its advantages of cost, mechanical properties of the welds and reliability have enabled the process to enter into areas once considered the sole property of resistance spot welding and riveting. This paper describes recent progress in industrial applications and is designed to give perspective to those considdering the process. Applications involving mild steel, high-strength steel, stainless steel, galvanized steel and aluminum are described.

Diversification in using gas metal-arc spot welding has come about by solving certain operating problems inherent in its use. For example, the introduction of slope-controlled power supplies has extended the reliability of this method of joining, and

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Paper presented at the AWS 42nd Annual Meeting held in New York, N. Y., during Apr. 17-21, 1961.

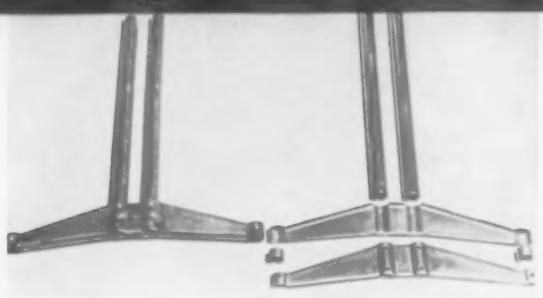


Fig. 2—Spot-welded unit of desk standard

recent work has indicated that rising voltage power supplies may also be of advantage for spot welding. Also, the use of reactance in the output circuit has considerably helped the process in many instances by reducing spatter to a minimum.

Another significant development has been the introduction of high quality welding wire. This high quality wire in particular has improved starting ability and has resulted in better welds. This is especially true in aluminum welding.

Along with these developments, laboratory and field development work has contributed much information on the process and the areas to which it may be applied.

Another reason for the wide acceptance of the process has been the fact that standard torches can be used when a timing function is incorporated in standard controls. Both for manual single torch applications and large multiple torch mechanized installations, the investment cost in equipment is less than for resistance spot welding.

Within the last few years, another variation of this spot-welding process, called "space welding," has been developed and introduced. Although not widely used at present, it presents an interesting and novel way of joining metal.

All of these developments and practices have spurred an interest in gas metal-arc spot welding. Its applications are many and varied as will be shown.

Industrial Uses of the Process

Metal Furniture

In the metal furniture field, gas metal-arc spot welding is now being used on steel for high speed production of modern school furniture. A desk standard of this type is shown in Fig. 1. The spot welds are sound and practically invisible. Each desk standard consists of two 1010 carbon steel base plates, two sections of welded seam tubing and two insert bushings. Figure 2 illustrates a unit that is spot welded in this fashion. Six spot welds are made on each side of the desk standard and, through the use of a rotary jig, all 12 spot welds are made in 15 sec. Including jigging, the production average is two desk standards per minute. The welds are clean and strong and require no weld preparation or postweld treatment.

Another prominent metal furniture manufacturer teams up the new spot-welding process with a unique positioner to produce 6000 spot welds per day. The positioner can be used to make tables, chairs or room dividers with a minimum of jigging time. One

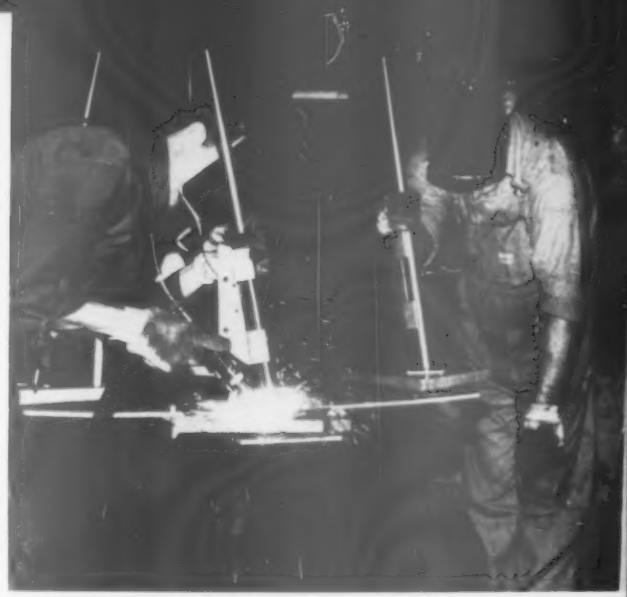


Fig. 3—Joining mild steel table legs to thick steel flanges

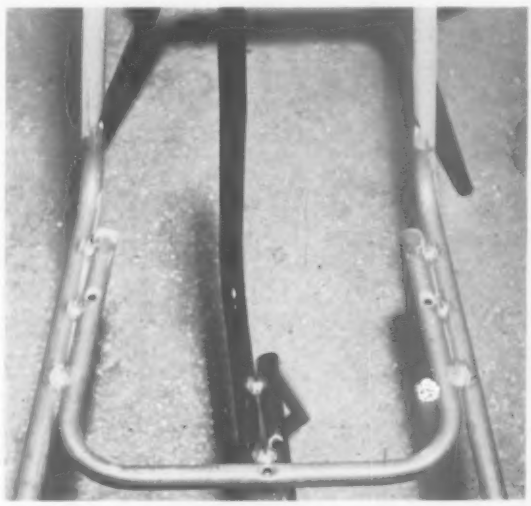


Fig. 4—Dinette chairs

of the operations, as shown in Fig. 3, is the joining of 10-gage mild steel table legs to $^1/_8$-in. thick steel flanges. Another operation, this time on chrome-plated metal chairs, led to a substantial saving in finishing costs. Whereas formerly a man was required to remove flux deposits, the gas metal-arc spot welds required no finishing and the chairs were ready for plating immediately after welding. The chrome adheres equally well to the base metal and the weld area.

At another manufacturing plant, dinette chairs as shown in Fig. 4 are constructed using the new process. Since the spatter-free welds do not disturb the paint adjacent to the weld area, chair frames are painted prior to welding. No postweld cleaning is necessary, and only six spot welds per chair are required. Bar swivel stools, on the other hand, of the type shown in Fig. 5 naturally must withstand more abuse than dinette chairs, so more

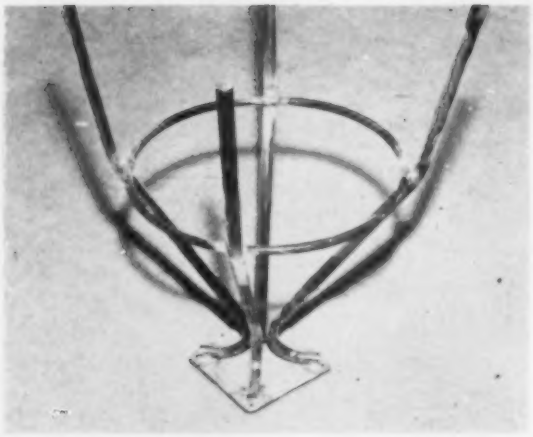


Fig. 5—Bar swivel stools

Fig. 7—Spot-welded stainless steel liner installation

Fig. 6—Wind tunnel sections

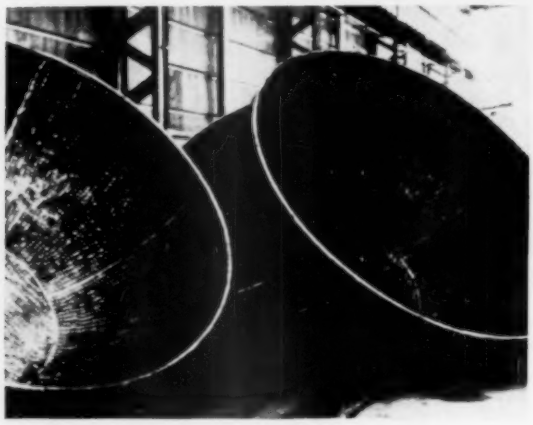


Fig. 8—Completed vessel head section

spot welds are required: four welds on the foot ring support and eight welds on the swivel section. This metal chair manufacturer has completely replaced other welding methods with the gas metal-arc spot-welding process. Since the production line has been tailored to the process, the exclusive use of the new spot-welding process at this company has increased production 125%.

Stainless-steel Liners

Besides the aforementioned industrial applications, many other interesting uses for gas metal-arc spot welding have been developed. For instance, in the design of heavy duty wind tunnels used for supersonic testing of aircraft designs, cost considerations have led to the use of high-tensile steel for the structural shell, with only a thin stainless-steel liner. Of course, the liner must be smooth for low resistance to supersonic air flow, yet must also withstand pressures up to 500 psi. Since only one side of the liner is accessible for welding, resistance spot welding, which generally requires access to both sides of the joint, is unsuitable. Gas metal-arc spot welding—the ideal process for spot welding stainless to high-strength steel—requires access to only one side of the joint to achieve fully penetrated spot welds; it also leaves the inside relatively smooth.

Four of these air receiver vessels for wind tunnel sections were assembled by a prominent manufacturer using the new spot-welding process. Each of these sections, as shown in Fig. 6, is 100 ft long with an $11\frac{1}{2}$ ft diameter. The vessel was lined with 4- × 9 ft sheets of Type 308 stainless steel, $\frac{7}{64}$-in. thick. Prior to lining, the outer shell was sandblasted on the inside to remove rust and scale. The stainless-steel sheets were then tacked in place

Fig. 9—Refrigerator frame front end assembly

and, after being preheated to remove any condensation, the seams were taped to keep out moisture. Final installation as shown in Fig. 7 was accomplished by spot welding on 1- × 1½-in. centers. Approximately 1,400,000 spots and 12,000 lb of Type 309 stainless steel wire were required for lining the four vessels. The average time was four welds per minute per man.

The completed lining was subjected to a pressure of 500 psi followed by vacuum testing. The spot weld acceptance rate was 99.5%. Figure 8 shows a completed vessel head section. Destructive tests on cut-out sections showed the spot liner could withstand over four times the expected pressure before yielding.

Air Conditioning

In another application, bolting methods used in air-conditioning fabrication were replaced with this modern way to join metals—and costs were reduced 50%. These 4- × 5- × 10-ft, air-conditioning units were previously assembled by braking the edges and bolting them together to form a rectangular box. Now with the use of gas metal-arc spot welding, the units are assembled with 240 spot welds made at a rate of 25 welds a minute. A job that previously took 40 minutes now takes less than 10.

Fig. 10—Attaching brackets to refrigerator frame

In addition to reducing actual fabricating costs, this process provided another bonus—whereas the bolted units became loose during shipment, the welded units remained solid and tight.

Refrigerator Frames

One of the features of the new spot-welding process is the reduction of fabrication time. This is indicated in the construction of commercial reach-in refrigerators and market merchandisers. One major manufacturer shifted to gas metal-arc spot welding to eliminate the costly and time-consuming metal-screw method which required:

1. Punched and dimpled holes.
2. Insertion of the metal screws.
3. Vapor sealing of the protruding screws.

These steps were eliminated by gas metal-arc spot welding with a production increase of 350% plus a more rigid frame. Formerly two men could produce 7 frames per day, now one man makes 12 frames per day. Figure 9 shows a front end assembly in which the weld must join 16-gage black iron, 20-gage galvanized steel and 16-gage creosote-coated channel iron. To maintain corrosion resistance, 1/16-in. silicon-bronze wire is used in this application. Brackets are attached to the side of the refrigerator frame in a fraction of the former time as shown in Fig. 10.

Expansion Joints

The potential of this spot-welding process was subjected to a severe test in the making of bellows-type expansion joints for the chemical industry. These joints, as shown in Fig. 11, consist of 28 separate pleats which are joined to form the completed assembly. They are used to compensate for temperature changes in fume stack ducts—an operation that requires the joints to endure extremes

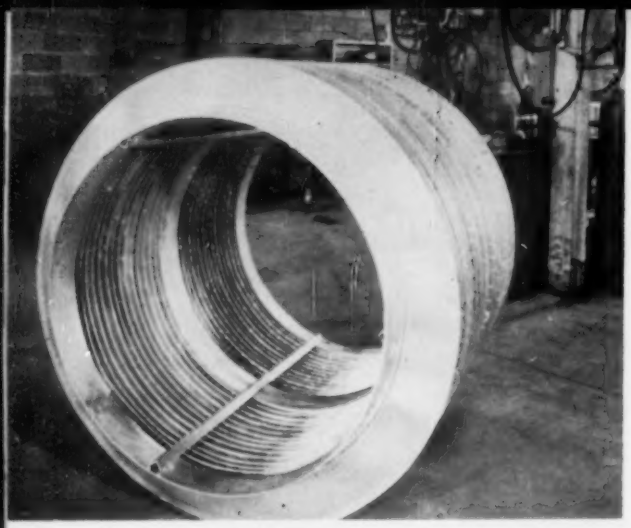


Fig. 11—Bellow-type expansion joints for chemical industry

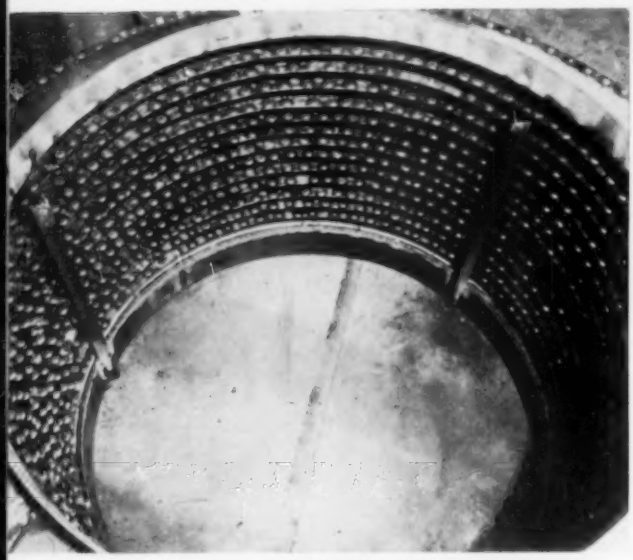


Fig. 12—Stack of spot-welded pleats—interior view

of expansion and contraction. Resistance spot welds quickly pulled apart under stress, whereas the spot welds made by the new process have been in service for over three years with no sign of failure. Figure 12 shows an interior view of a stack of spot-welded pleats. Each pleat is fabricated with close to 200 spot welds made with $^1/_{16}$-in. diam deoxidized mild steel wire.

Pedestal Floors

Gas metal-arc spot welding has even entered the computer field. In the installation of these giant electronic brains, the maze of interconnecting cables presents a serious installation and safety problem. To overcome this, raised pedestal floors were developed. Figure 13 shows an installation of this type. The aluminum panels support the computer installation while concealing ducts and cables. Additional machines will be placed over the openings shown in the foreground. Each panel weighs only 4 lb per sq ft and is made of 6063T6 aluminum.

Fig. 13—Raised pedestal floor installation

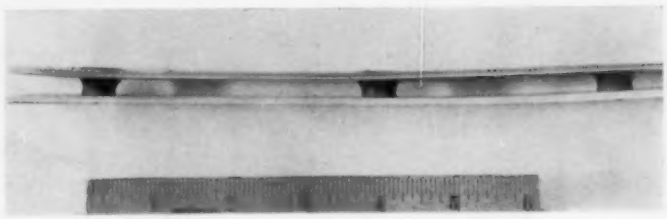


Fig. 14—"Space welding"

Panels ranging from 18 to 48 in. long and from 18 to 36 in. wide provide custom-made floors at prices comparable to prefabricated floors. Economical assembly with gas metal-arc spot welding makes this possible.

Space Welding

Another unique variation of the process—space welding—has also been successfully applied, although to a limited degree. In this method of joining, two parallel sheets are joined by spot welding, leaving a $^1/_4$ in. maximum space separating the sheets. An interesting result was reported when two sheets of $^1/_{16}$-in. thick carbon steel required almost twice the force per unit of deflection as did one sheet of $^1/_8$-in. thick carbon steel of the same weight.

This "space" spot-welding process was originally developed for spot welding of Type 304 stainless steel in making cold wall dimple sheets for refrigerated milk tanks. Both arc plug welding and resistance projection welding were tried, but sufficient bursting strength could not be obtained with either method. These two methods, namely projection welding and plug welding, differ from "space welding" in the following ways:

Fig. 15—Special mechanized spot-welding equipment for cargo containers

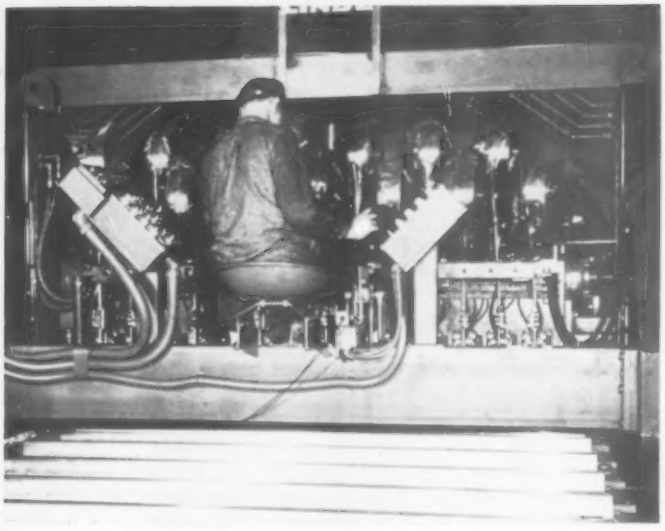
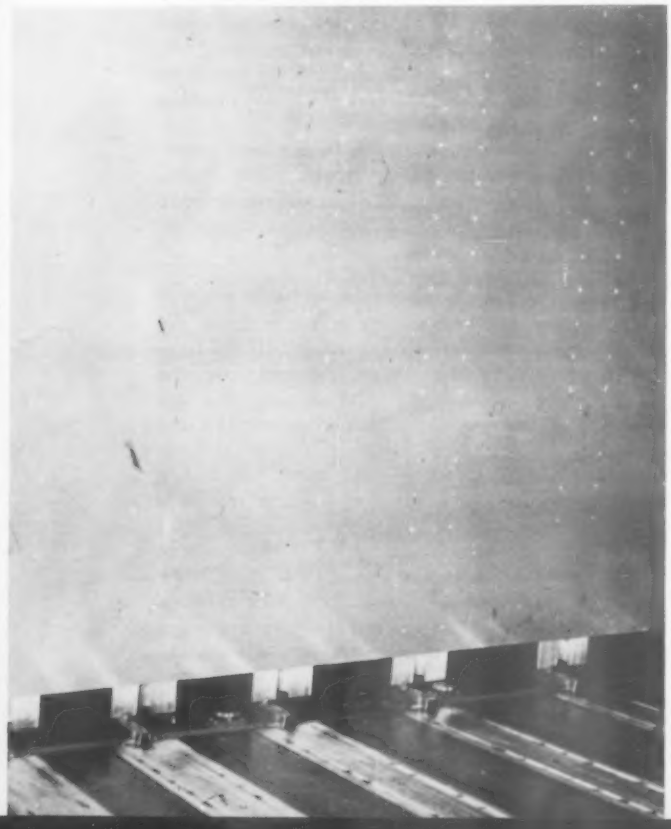


Fig. 16—Position for spot welding posts on cargo container

Fig. 17—Side sheet for spot-welding on cargo container



1. In resistance projection welding, projections must be made in one of the sheets to be joined so there will be points of control to localize the current and pressure when the sheets are spot welded.
2. Arc plug welding requires that holes be made in one of the sheets to be joined and the weld be made through these holes, which are filled up by the weld metal.
3. In "space welding," shown in Fig. 14, standard gas metal-arc spot-welding equipment is used to melt a hole in the top sheet. The arc fuses the lower sheet and a column of metal is built up; this fuses into the hole in the top sheet. This method produces a large fused area in the lower sheet with no preparation other than the insertion of spacers between the two sheets.

Space welding can be used effectively on many of the materials that can be welded by this process. An important exception, in so far as space welding is concerned, is aluminum, for which the process has not yet been developed. The space-welding process has been successfully applied both to stainless steel and to carbon steel.

Some applications of this process require single-cycle spot welds. For others, especially with larger spaces, double-cycle gas metal-arc spot welding is necessary. The nuggets built up are very uniform. However, fusion into the lower sheet is not necessarily equal to the diameter of the nugget at that point. If any cold lap does occur, this can be eliminated by making another spot weld through the lower plate. In effect, this places a button on each side of the assembly.

Cargo Containers

Gas metal-arc spot welding has found acceptance in the automotive industry in varied applications. While some of these results are well known and the applications well established, there are other areas where results with the process approach the spectacular. For example, one major manufacturer of rail cars and automotive subassemblies is engaged in the manufacture of all-welded aluminum cargo containers for shipboard transportation. These containers, which are 30 ft long, are constructed to take load limits of 70,000 lb, although the container itself weighs only about 3500 lb.

During the manufacture of these containers, special mechanized spot-welding equipment is used as shown in Fig. 15. This gantry, which has 14 spot-welding torches, rides along tracks and automatically welds the hat-shaped rib-post stiffeners for roofs, sides and ends onto the 6061 aluminum-base sheets. The copper bars shown in the foreground chill the spot and are also grooved to allow full penetration for maximum strength. Figure 16 shows the welder in position for spot welding of posts onto a side sheet of the container. These posts are 0.090-in. 6061 extrusions, and the side sheet is 0.080 in. thick. Spots are spaced on approximately 3-in. centers, and shear values in excess of 700 lb are obtained.

The lead photograph shows a closeup of the

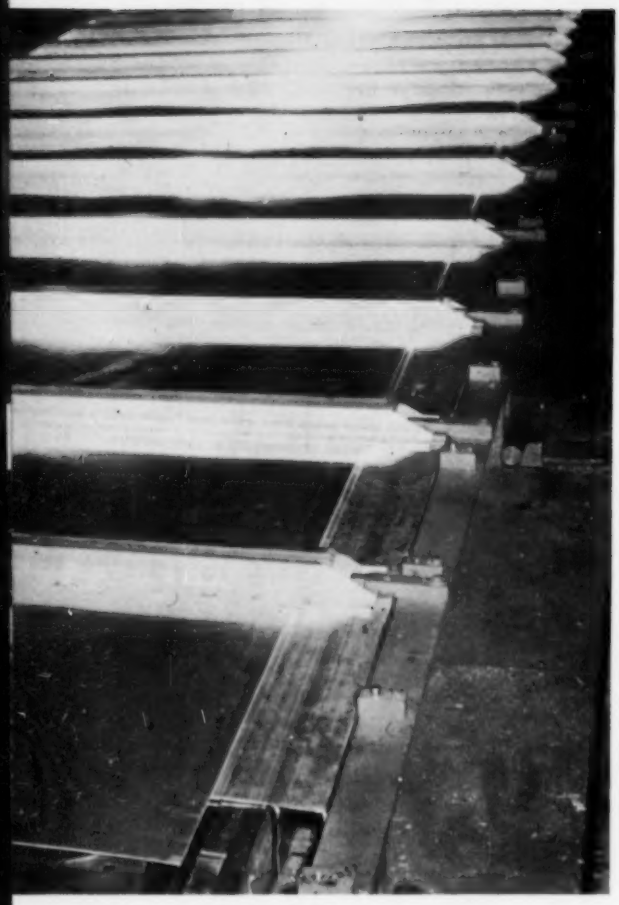
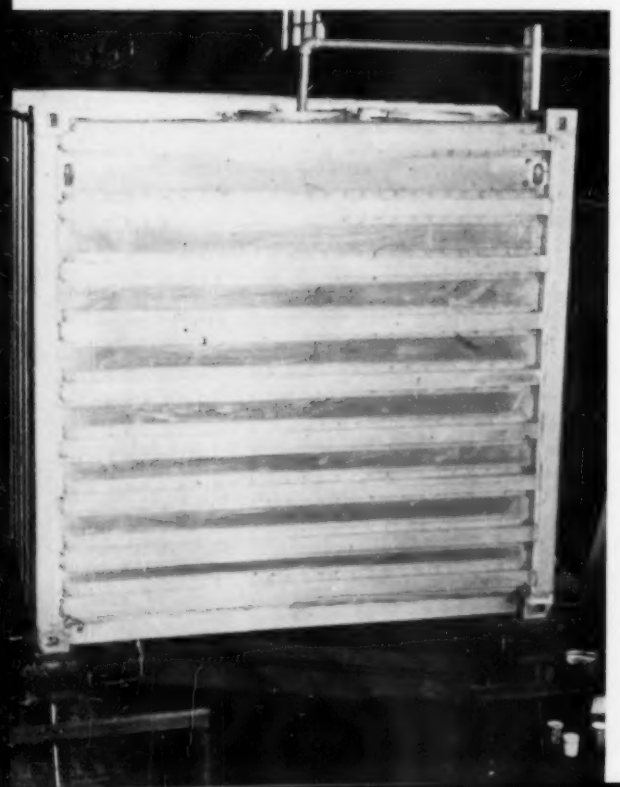


Fig. 18—Cargo-container roof

Fig. 19—Completed cargo container undergoing static test



machine. For this application, 14 coils of 4043 $^{1}/_{16}$-in. aluminum were used. In the foreground may be seen completed rows of spots. Figure 17 shows the backside of a side sheet for spot welding. Here the full penetration without distortion should be noticed. The relieved copper back-up bars are clearly shown. Figure 18 shows a roof which has been completed. Here the roof carlings are 0.080-in. extrusions, and the roof is $^{1}/_{16}$-in. 6061 aluminum.

The spot-welding machine is capable of spot welding all the posts and carlings on a side and a roof in a continuous row, allowing for maximum utilization of the process. The end rib-post stiffeners to end sheets of the box are also spot welded on the same fixture.

When completed, the container has over 4200 spot welds, all made automatically. All welds exceed the shear strength requirements, and surface appearance is acceptable on all welds. Because of the interior finish required, all spot welds are flush ground on the bottom side and examined for cracks and porosity. Any hole or crack capable of retaining a 300 mesh particle is considered rejectable. Even with the strict requirement, the average reject rate is less than 2%. Of particular note on this application is that $^{3}/_{4}$ of all welds are made from a thick-to-thin member.

The magnitude of this operation can be realized when it is considered that, on this one order alone for cargo containers, the number of spot welds will exceed 3,500,000. Leak tightness far beyond that associated with riveting is obtained, and the welds are as corrosive resistant to salt spray as the base material. Figure 19 shows a completed container undergoing static testing.

Although riveting was not considered for this application due to the stringent requirements, a study by a leading aluminum producer indicates that based on unit cost per rivet and per spot, gas metal-arc spot welding costs about 50% less than riveting and impact values exceed those obtained with resistance spot welding and riveted construction. Fatigue values were shown to be higher than resistance welds and comparable to rivets. Cost analysis studies show a reduction in requirements from 18 to 6 for the same output.

Conclusion

In summary, it can be seen that, in its six years of growth, many applications in industry have developed for gas metal-arc spot welding. These have resulted in reduced labor time, reduced cost and a higher quality product. The applications are varied and numerous—aluminum boats, window and door frame construction, radar antennas, grating, general architectural work—and these are but a few of the places where this spot welding process is today being successfully applied.

Practically no skill is required for the operator to produce consistent results. This combination, then, of high production, lower cost and high quality, should work to establish gas metal-arc spot welding even more firmly as a modern way to join metals.

Fixture for locating and tacking the aluminum extrusions to the end sheet

Approximately 6000 tons of aluminum plate together with 173,000 lb of welding wire and 3,350,000 cu ft of argon were required to fill an order in the

Welding of **Aluminum** Gondola Cars

BY B. KARNISKY AND W. G. BOESE

The subject of aluminum welding is not new. However, its application in the full-scale assembly-line production welding of 16 cars per day was a new development. This is the production rate that was attained with an order for 750 100-ton capacity aluminum gondola cars for the Southern Railway System.

Railroad cars are subjected to extremely complex conditions of impact and fatigue stresses, coupled with low temperature and corrosive environments. Gondola cars are also subjected to considerable abrasion. Under these conditions, aluminum was expected to have several advantages, principally as to impact and abrasion resistance. From past experience, 5083 (Al-Mg-Mn) alloy was recommended specifically for these cars because of the ease of welding and fabrication, retention of high strength and ductility in the joint, and satisfactory performance in various corrosive atmospheres.

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Paper presented at Seventh Annual Midwest Welding Conference, Armour Research Foundation, February, 1961.

Engineers from Pullman-Standard, the Reynolds Metals Co., and the Southern Railway System collaborated on the design of the 100-ton gondola car. These jumbo cars were to be used by the railroad for coal service to obtain maximum payload per trip. They were to be unloaded by means of a rotary dumper, which literally turns over the gondola to empty it and thus subjects the side of the car to a considerable portion of the total load.

To construct the 750 gondola cars required about 6000 tons of aluminum plate, a total of 173,000 lb of aluminum welding wire, and 3,350,000 cu ft of argon. Utilizing 8000 man-hours per day, 16 cars per day were readily completed. This was, however,

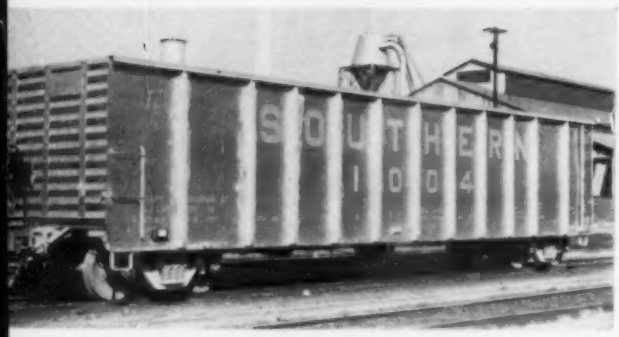


Fig. 1—General appearance of the exterior of the 100-ton capacity aluminum gondola cars

Fig. 2—Interior of the gondola car. The diagonal side braces and the horizontal braces were all constructed of aluminum pipe

accomplished only by converting massive steel production plant facilities to aluminum fabrication and welding, with a minimum disruption in submerged-arc welding equipment and fixtures.

Design and Specifications

All of the principal subassemblies were of aluminum construction except the mild steel center sill, which was a standard Z-26 section with welded draft lugs and strikers. The aluminum crossbearers, crossties and bolsters were attached to the center sill by means of an intermediate steel section riveted to the aluminum and welded to the center sill webs. All faying surfaces were painted with zinc chromate primer and a suitable lap-and-joint compound before riveting. The continuous top cover plates of the bolsters and crossbearers were also riveted to the top of the center sill. The floor sheet, side sheets and end sheets were one-piece, thereby eliminating any butt welds. Likewise, all special extrusions developed for the posts and sill sections were made the required length. Thickness of the aluminum varied from $^3/_8$ in. for the large sheets to $^3/_4$ in. for the bolsters.

The use of extrusions adapts itself readily to a welded design consisting mainly of fillet welds. Butt welds may reduce the amount of welding, but there is always the possibility of not getting complete fusion at the root unless the spacing of the joint can be maintained accurately while welding. Therefore, most of the welding was designed for single-pass $^1/_4$- $^5/_{16}$- or $^3/_8$-in. fillets. These joints were welded on both sides to reduce the stress concentrations at the root of the fillet welds. At locations of high stress, special precautions were taken in the design and procedure for welding of corner intersections and weld terminations. Here, use was made of experience gained with steel weldments through numerous impact and fatigue tests with full-size cars.

Table 1—Comparison of Over-all Dimensions and Capacities of the 100-ton Aluminum Gondola Car with Conventional 70-ton Steel Hopper Car

	100-ton aluminum gondola car for Southern Railway System	70-ton PS-3 hopper car for Louisville and Nashville RR
Length inside	47 ft 8 in.	42 ft 10 in.
Length over strickers	49 ft 5 in.	43 ft 10 in.
Width inside	9 ft $6^7/_8$ in.	9 ft $7^3/_4$ in.
Width over side top chord	10 ft $4^1/_2$ in.	10 ft $5^3/_4$ in.
Height inside	8 ft 0 in.	.....
Height rail to top of side	11 ft $6^5/_{16}$ in.	10 ft $8^1/_{16}$ in.
Wheels	36 in.	33 in.
Truck centers	38 ft 5 in.	33 ft 10 in.
Cubic capacity, level full	3620 cu ft	2750 cu ft
Light weight of body	26,300 lb	35,860 lb
Light weight of trucks	21,000 lb (100 ton capacity)	17,040 lb (70 ton capacity)
Total light weight of car	47,300 lb	52,900 lb
Rail load of car	251,000 lb	210,000 lb
Load capacity	203,700 lb	157,000 lb
Ratio of load capacity, lb, to total light weight of car	4.3 lb	2.97 lb

Figure 1 is a general over-all view of the exterior of the gondola car. As can be seen, this is a simple coal car, but the unusual feature is the huge capacity. This is the first 100-ton car designed and built by Pullman-Standard, and the first aluminum construction job of this magnitude.

Figure 2 is an interior view, showing the diagonal and horizontal braces constructed of aluminum pipe. These additional side braces are necessary, because the cars are used in a rotary dumper to expedite unloading.

In Table 1, the over-all dimensions of the 100-ton aluminum gondola car (designed with a 3620 cu ft capacity) may be compared with a standard 70-ton steel hopper car of 2750 cu ft capacity. The important point emphasized here is the total weight of 47,300 lb for the aluminum car, with a capacity of 203,700 lb, or a ratio of 4.3 lb of load capacity per pound of car. The steel car, on the other hand, with a total weight of 52,900 lb and a load capacity of 157,000 lb has a ratio of 2.97. In other words, the aluminum car will haul 45% more payload than an equivalent weight steel car.

The proportion of steel and aluminum for the gondola car is shown in Table 2. As may be seen, a total of 7524 lb of steel and 15,739 lb of aluminum was used; a portion of this aluminum consisted of 5015 lb of extrusions. The extrusions were 5083-H112 aluminum alloy and the plates were either 5083-H113 or 5454-H34 aluminum.

Table 3 is a general list of material requirements for the car. A total of 223 lb of various sizes of aluminum welding wire are listed in this table. An estimated 5000 cu ft of argon were consumed. Actually, 19.3 cu ft of argon shielding gas per lb of welding wire were used.

Table 2—Proportion of Aluminum and Steel Used for Construction

	100-ton aluminum gondola car
Steel	
Shapes	5064 lb, OHS, center sills
Plates	1241 lb, OHS, draft sill parts
Sheets	10 lb, OHS, support rods, levers
Bars	1209 lb, OHS, end construction to center sill
Total	7524 lb
	70-ton PS-3 hopper car
Shapes	9,209 lb, OHS
Shapes	698 lb, HSS
Plates	5,065 lb, OHS
Plates	16,077 lb, HSS
Sheets	11 lb, OHS
Bars	1,466 lb, OHS
Total	32,526 lb
Aluminum	
Extrusions	5,015 lb, alloy 5083-H112
Plates	2,402 lb, alloy 5454-H34
Plates	7,336 lb, alloy 5083-H113
Bars	87 lb, alloy 6061-O
Bars	10 lb, alloy 5083-H112
Pipe	889 lb, alloy 5083-H112
Total	15,739 lb

Selection of Size and Type of Aluminum Alloy Wire

During the testing of any welding wire or electrode, the test conditions must duplicate the actual production welding conditions as much as possible. One of the greatest complicating variables in aluminum welding is variation in the type and quality of

Table 3—Materials and Thicknesses Used for Construction of the Various Car Components

	100-ton aluminum gondola car	70-ton PS-3 hopper car
Center sills	OHS-Z-26 section @51.2 lb	.....
Floors	3/8-in. aluminum	1/4-in. HSS—End floor sheet 5/16-in. HSS—Intermediate floor sheet and at cross ridge 3/8-in. HSS—Hopper chute and hoods
Side sheets	3/8-in. aluminum	1/4-in. HSS
Side stakes	Aluminum extrusion	1/4-in. HSS—Pressed channels 5/16-in. HSS—Pressed channels at bolster and cross ridge
End sheet	3/8-in. aluminum, with extruded aluminum horizontal stiffener	.....
Rivets	355 lb, OHS	195 lb, OHS
Welding rod, steel	147 lb	528 lb
Welding rod, aluminum	110.0 lb, 1/8-in. 5556 wire	.....
	110.0 lb, 3/32-in. 5556 wire	.....
	1.0 lb, 1/16-in., 5556 wire	.....
Shielding gas	5000-cu ft argon	.....
Bolts and nuts	Securing aluminum parts are aluminized and dipped in Zincilate before application	Steel
Paint	No paint except steel parts of underframe	One primer and one coat hot spray on outside

finish on welding wire. On the basis of tests, Type 5556 aluminum alloy wire was ordered to Military Specification MIL-E-16053G, employing the bright or zincate finish.

Preliminary test welds were made with 17 different types of sources of aluminum wire; by simply breaking and examining these welds, the superiority of the Type 5556 wire was established. Of course, numerous physical property tests were made to establish its superiority over the Type 5356 wire, which was commonly being used for this type of application. During the preparation of test specimens, wire-brushed and nonbrushed plate surfaces were welded with both 60 and 45 cfh of argon shielding gas. This provided a range of properties so that it was possible to establish how stringently the actual production welding conditions must be controlled.

Operation and Weld Cleanliness Tests

For production welding, the car would be positioned either horizontal or flat for predominantly lap or fillet welds. Test specimens selected were $^3/_8$-in. single-pass and $^1/_2$-in. three-pass horizontal lap welds. These test welds were broken and examined with the binocular microscope. During testing, sound horizontal lap welds were observed to be more difficult to make than fillet welds because of the loss of shielding gas.

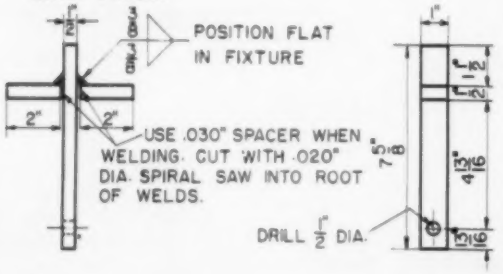
For the aluminum bridge and gondola cars previously constructed at another plant, Type 5356 wire was used with an argon plus-helium mixture for shielding gas. This mixture provided a sounder weld than could be obtained with argon alone, and it was a prerequisite in order to pass the stringent vertical and overhead qualification test requirements.

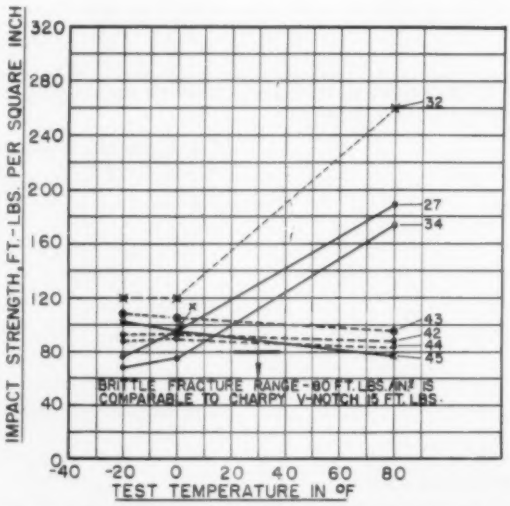
With the current test welds, the same difficulties and large scattered porosity were again encountered when using $^1/_{16}$-in. 5356 wire and argon. In this case, it was impossible to obtain the helium mixture for the large number of cars involved. Numerous current and voltage variations were tried without success. By increasing the diameter to $^3/_{32}$ in., and using as high a current as practical, however, the welds became much cleaner. The lesser surface area (containing oxides and moisture to introduce porosity) and the reduction of the cooling rate of the weld metal could be two possible reasons for this improvement. An increase in depth of penetration and a 20% increase in welding speed were two additional improvements gained by the increase in wire size. These same improvements, including speed, were observed in the automatic welds after changing from $^3/_{32}$- to $^1/_8$-in. diam wire.

At this time, samples of Type 5556 wire, which had been developed recently, were received. The welds made with this wire, using the $^3/_{32}$ in. size, were much cleaner than with the 5356 wire with the same type of finish. In fact, the finely scattered porosity had the same appearance as in welds previously made with the helium mixture. After similar results were obtained with wire from other sources, it was decided to make more complete physical property tests of Type 5556 wire.

LIST OF ELECTRODE TESTS

32 DOUBLE HEAD SUBMERGED ARC, $\frac{5}{32}$ IN. L 60 WIRE AND 780 FLUX.
27 $\frac{5}{16}$ IN. E-6020 ELECTRODE.
34 $\frac{5}{16}$ IN. E-6012 ELECTRODE.
43 $\frac{3}{32}$ IN. 5556 ALUMINUM WIRE, LOT NO. 7764-B, BRIGHT FINISH.
42 $\frac{3}{32}$ IN. 5556 ALUMINUM WIRE, LOT NO. 138911, BRIGHT FINISH.
44 $\frac{3}{32}$ IN. 5356 ALUMINUM WIRE, LOT NO. 466022, BRIGHT FINISH.
45 $\frac{3}{32}$ IN. 5356 ALUMINUM WIRE, LOT NO. F-348, SATIN FINISH.





DOUBLE-T FILLET WELD TENSILE IMPACT TEST SPECIMEN - THE PLATES ARE 24 IN. LONG, THE WELDS 20 IN. LONG, AND ALL ARE MADE WITH THE SAME HEAT INPUTS. WELD ONE SIDE, COOL, THEN WELD THE OTHER SIDE IN THE OPPOSITE DIRECTION. FOUR SPECIMENS, CUT AT RANDOM, ARE BROKEN AT EACH TEMPERATURE AND THE RESULTS ARE AVERAGED.

Fig. 3—Results of double-T fillet weld impact tests of various steel and aluminum welds

Table 4—Result of Lehigh Restraint Tests of 1/2-in. 5083-H113 Aluminum Plate Welded with Various Wires and Conditions

Changes in procedure or welding technique	Type of wire	Source of wire	Size of wire, in.	Argon, cfh	Amperes	Volts	Restr., in.	Temperature, °F	Cracking	Brinell hardness — PM	Weld	Heat-affected zone	Remarks
Normal procedure	5356	A	1/16	50	260 DCRP	29	8	70	None	"	...	...	Very slight porosity
Reduced argon flow	5356	A	1/16	35	260 DCRP	29	8	70	None	"	...	...	Considerable fine porosity
Welding with leading angle on gun	5356	A	1/16	35	260 DCRP	29	8	70	Crater crack	"	...	...	No porosity
Normal procedure	5356	B	1/16	50	260 DCRP	29	8	70	Crater crack	"	...	...	Very slight porosity
Normal procedure	4043	C	1/16	50	260 DCRP	29	8	70	100 %	"	...	...	Very slight porosity
Normal procedure using Lincoln 400 amp motor generator	5356	D	1/16	55	245 DCRP	28	8	65	None	80	60–67	73–76	Fine porosity only
Welding with leading angle on gun and 400 amp M. G.	5356	D	1/16	55	240 DCRP	28	8	60	Crater crack	80	62–80	71–74	Fine porosity only
Normal procedure	5556	D	1/16	55	250 DCRP	28	8	65	None	80	72–80	71–76	Fine porosity only

Note: Plates with 3 1/2-in. long slots were milled with a 1/4-in. radius, 1/4-in. deep, and welded with a single pass.

Lehigh Restraint Tests

Lehigh restraint tests were made using 1/2-in. 5083-H113 aluminum plate. The specimen was a full 8 by 12 in. size with a 3 1/2-in. long slot. Using this test, various types of wire with varying amounts of argon flow and push-versus-drag techniques were tried. This is a test of crack sensitivity as the weld metal cools under a condition of high restraint. Normally, this is a standard test for qualifying and checking arc welding electrodes and submerged-arc wires and fluxes. With all the aluminum tests conducted, the only weld that cracked severely, as shown in Table 4, was made with Type 4043 wire. Using 5356 wire and decreasing the argon flow from 55 to 35 cfh did not affect the cracking. Although there was considerable fine porosity in the weld, the weld metal was still crack-resistant with the lowest argon shield.

Fillet Weld Impact Tests

Some time ago, a fillet weld impact test was developed to study the effect of welding variables on the impact properties of various steel electrodes. This is essentially a test of a single-pass dendritic structure in contrast with a three-pass specimen usually required for Charpy impact testing. The latter, of course, contains a mixture of refined zones, which is not always representative of actual production welding. A sketch of the test specimen is shown in Fig. 3. Usually, four specimens are broken at each of three temperatures in order to obtain the transition temperature curves, also shown in Fig. 3.

Using 5083-H113 aluminum plate, impact tests were carried out with 5556 wires obtained from two sources to compare with 5356 wires from two different suppliers. Because of the higher tensile strength of 5556 wire, it seemed reasonable to assume that the elongation and ductility of welds made with it might be lower than with 5356. As can be seen from the plotted results, there is no significant difference except that the 5556 welds are slightly better. Data for steel welds are also plotted, and at room temperature their impact values are considerably higher than the aluminum welds. The difference in tensile strengths partially accounts for this difference in impact strength. At low temperatures, where the steel welds undergo a transition and fail in a brittle manner, there are no changes in the impact properties of the aluminum welds. In other words, these tests indicated an advantage in the use of welded aluminum for structures subjected to low temperature impact service.

Butt Weld Tensile Tests

Butt weld tensile test specimens were made using 5556 wire and 1/2-in.-thick 5083-H113 aluminum plate. The edges of the plates were beveled for a 60-deg included angle. Either a grooved steel back-up or an aluminum back-up plate was used. The spacing or root opening was wider for hand welds than the spacing for automatic welds. Three

Table 5—Comparison of Mechanical Properties of Butt-Welded Joints in 1/2-In. Aluminum Alloy Plates Made with 5356 and 5556 Filler Wires

Changes in procedure or welding technique	Type of wire	Source of wire	Size of wire, in.	Argon, cfh	No. of passes	Specimens machined all over to 1 1/2-in. wide and 1-in. gage length: Tensile strength, psi	Yield strength psi	Elongation % in 1-in.	Joint efficiency, %	Location of fracture	Specimens 1 1/2-in. wide and 4-in. gage length, weld crown and root not machined: Tensile strength, psi	Yield strength, psi	Elongation % in 4-in.	Joint efficiency, %	Location of fracture
Parent metal, 1/2-in. 5083-H113 aluminum plate (spec. 1/2-in. wide and 2-in. gage length)	...	..	..	..	..	52,100	39,400	15.0	100	45-deg shear failure	51,250	37,600	12.7	100	45-deg shear failure
Results quoted for 1/2-in. 5083-H113 butt welds[a]	5083	..	1/16	..	..	39,200	19,700	13.6	87	Weld metal	40,600	21,800	12.5	90	Fusion line
Normal procedure, wire brushed	5356-Z	A	3/32	60	2	42,100	25,000	21.0	81	Weld fusion line, no visible porosity	44,400	23,550	7.0	87	Weld, near fusion line, no visible porosity
Automatic weld, normal procedure	5356-Z	A	3/32	60	2	42,900	24,800	21.0	82	Weld, near fusion line, no visible porosity	41,600	25,150	5.7	81	Weld, near fusion line, no visible porosity
Parent metal, 1/2-in. 5083-H113 Al plate	...	..	..	..	..	46,500	31,350	19.0	100	.....	47,300	26,850	13.7	100	.....
Aluminum not brushed	5556	B	1/16	60	3	44,550	29,550	21.5	95	Weld, no porosity	46,150	25,100	13.4	98	Parent plate, heat-affected zone
Reduced argon shield, wire brushed	5556	B	1/16	45	3	42,800	27,250	19.0	92	Weld, some large porosity	45,000	21,000	11.8	95	Parent plate, heat-affected zone
Reduced argon, plate not brushed	5556	B	1/16	45	3	43,300	27,800	21.0	93	Weld, near fusion line, slight porosity	44,150	21,000	10.1	93	Weld, near fusion line, slight porosity
Automatic weld, normal procedure	5556	B	3/32	60	1	43,050	24,700	24.5	93	Weld, near fusion line, no porosity	43,200	21,400	10.5	93	Weld, near fusion line, no porosity
Parent metal, 1/2-in. 5456-H321 Al plate	...	..	..	..	..	55,300	44,000	12.0	100	45-deg shear failure	56,100	38,700	10.5	100	45-deg shear failure
Normal procedure, wire brushed	5556	B	1/16	60	3	43,800	31,300	14.0	79	Weld, near fusion line, some medium and large porosity	44,700	28,800	5.0	80	Weld, along fusion line, no visible porosity

Note: Bevels on the plates were machined with a sharp nose for a 60-deg included angle joint. They were welded on a grooved steel back-up plate with an inert-gas metal-arc hand gun.

[a] "Properties of Welds in Al-Mg-Mn Alloys 5083 and 5086," by L. A. Cook, S. L. Channon and A. R. Hard, The Welding Journal (February 1955).

passes were required for the 1/16-in. wire hand welds, but two passes were sufficient for the 3/32-in. wire. On the other hand, the automatic welds using 3/32- or 1/8-in. wire were made in one pass. The welding conditions were also varied in order to obtain a range of properties. These results are tabulated for comparison in Table 5.

Also shown in Table 5, for comparison, are the results quoted for 5083-H113 aluminum butt welds made with an alloy similar to but not the same as 5356. Even with the various conditions of specimen preparation, butt weld tensile strengths associated with 5556 exceeded 42,800 psi, the yield strengths ranged from 24,700 to 29,550 psi and the elongations ranged from 19 to 24.5%. These results may be compared with the quoted values of 39,200 psi, 19,700 psi and 13.6%, respectively. Therefore, results indicated that the 5556 wire is a satisfactory substitute for 5356 and has the added benefit of more elongation in the joint. Needless to say, numerous other physical tests were made to confirm this.

Butt welds prepared with lack of fusion at the root were included to illustrate the drastic effect of a notch introduced in the weld specimen. The additional stress concentration induced by the weld crown and the lack of fusion resulted in a reduction of tensile strengths and very low elongations. Sufficient width of joint opening must be used for butt welds to obtain proper penetration and fusion at the root. In addition, a low arc voltage will minimize the tendency to bridge across the joint.

In Table 5, the results are listed for the tensile tests of 5356 and 5556 butt welds made with automatic equipment. Here, again, the test results obtained for 5556 wire were slightly higher. As the yield and tensile properties of the weld approach those of the parent plate, more of the plate itself will be put to work in the joint, resulting in higher elongations. This reasoning was verified by making 5556 welds on 5456-H321 plate. Here, by using a parent plate with properties considerably higher than the weld,

Table 6—Transverse Shear Strength of 5556 Fillet Welds with Various Welding Procedures

Changes in procedure or welding technique	Type of wire	Type of transverse fillet shear test[a]	Process for welding	Plate surfaces brushed	Argon cfh	Fill size, in	Shear strength, lb per lin. in.	Change in strength, %	Location of fracture
Quoted value for 5556 wire	5556	...	...	..	..	5/16	9,000	100	.....
Quoted value for 5356 wire	5356	..	..	..	..	5/16	7,500	83	.....
Normal procedure	5556	Single fillet	Semi-automatic	Yes	60	5/16	9,500	105	Weld, shear, some small root porosity
No wire brushing	5556	Single fillet	Semi-automatic	No	60	5/16	7,000	78	Weld, shear, continuous root porosity, small and medium
Reduced argon flow	5556	Single fillet	Semi-automatic	Yes	45	5/16	8,700	97	Weld, shear, very little porosity
Reduced argon and not brushed	5556	Single fillet	Semi-automatic	No	45	5/16	7,800	87	Weld, shear, very little porosity
Normal procedure	5556	Double fillet	Semi-automatic	Yes	60	5/16	10,700	119	Weld, shear, very little porosity
No wire brushing	5556	Double fillet	Semi-automatic	No	60	5/16	8,200	91	Weld, shear, continuous small root porosity
Reduced argon flow	5556	Double fillet	Semi-automatic	Yes	45	5/16	8,200	91	Weld, shear, slight root porosity, some porosity in top of weld
Reduced argon and not brushed	5555	Double fillet	Semi-automatic	No	45	5/16	7,300	81	Weld, shear, continuous small root porosity, some porosity in top
Quoted value for 5556	5556	...	...	...	..	1/4	7,200	100	.....
Normal procedure	5556	Double fillet	Automatic	Yes	60	1/4	8,700	121	Weld, shear, no root porosity, a little small porosity in weld
Quoted value for 5556	5556	...	...	...	..	3/8	10,800	100	.....
Normal procedure	5556	Double fillet	Automatic	Yes	60	3/8	10,800	100	Weld, shear, slight root porosity

[a] The 1/2-in. 5083-H113 plates were lap welded for the single-fillet transverse shear tests. The double fillet welds, with 1/2-in. plates, were standard AWS specimens made according to the recommended practice. All were single pass welds, and specimens 2 1/2 in. wide were cut for testing.

comparatively lower elongations were obtained as shown in Table 5.

Fillet Weld Shear Tests

Because of the number of fillet weld shear tests made, it is possible to cover only salient points here. Two types of transverse shear tests were made using 1/8-in. 5083-H113 plate. One was a simple lap fillet weld, while the other was a standard double fillet weld specimen. Any weakening of the parent plate occuring as a result of welding on opposite sides would be observed in the results of the double fillet weld test. However, no difference was observed in these tests. By using a special holding fixture to keep the plates from spreading during the test, the single fillet lap weld gave adequate results.

The shear strengths per lineal inch for 5/16-in. fillets as shown in Table 6 exceeded the 9000 lb value quoted for 5556 wire. These results were considerably higher than the shear strength of 7500 lb quoted for 5356 wire. These test plates were made with the standard procedures wherein the plate surfaces were wire brushed before welding and 60 cfh of argon used.

Another comparison of shear strengths was made with single pass 5/16-in. fillets prepared with different conditions. These results are also shown in Table 6. A slight reduction in shear strength was observed for specimens welded with 45 cfh of argon and a larger reduction for specimens prepared without wire brushing. However, the lowest values obtained under these conditions were almost equal to the results quoted for 5356 wire. In other words, using 5556 wire, considerable variation from optimum welding conditions can be tolerated without loss of reasonable physical properties.

Development of Welding Procedures

The welding procedures for the various joints were worked out in detail in the laboratory, and the desirable changes were made on the drawings. The objective for these procedures was to obtain optimum quality at maximum speed of production. From observation of the results of the tests on various types of wire, 3/32-in. wire was selected as the standard for hand welding and 1/8-in. wire for automatic welding.

A few typical procedures are listed in Table 7 and, applied on the gondola cars, proved satisfactory with only minor changes. Data that were obtained for 1/16-in. wire were included in this table for comparative reasons. The welding speed was 13.4 ipm for a 3/8-in. lap weld made with 1/16-in. wire. This speed was increased progressively to 17.4 and 34.0 ipm by increasing the diameters of the wire to 3/32 and 1/8 in., respectively.

Welding Equipment and Procedure

Selection of Equipment

The conversion of massive steel production facilities to aluminum fabrication and welding was an engineering accomplishment of considerable magnitude. This conversion was attained with minimum change in fixtures, submerged arc welding equipment and other facilities.

The equipment for freight car construction had to be rugged and dependable in order to give the best performance and quality of welding. All of the available types of semiautomatic welding equipment, and power sources, underwent thorough comparative testing in the laboratory. Numerous test welds were made with the same conditions used previously

Table 7—Typical Welding Procedures Developed for Gondola Car Construction

Type of joint	Process for welding	No. of passes	Type of wire	Argon, cfh	Amperes	Volts	Fillet size, in. Vertical	Fillet size, in. Horizontal	Fillet size, in. Thr.	Weld travel speed, ipm	Wire consumed, lb per foot of weld
5/16-in. 5083 Al butt joint, 3/8-in. Al back-up, 5/16-in. spacing	Automatic	1	1/8-in., 5556	65	450 DCRP	24 1/2	...	..	..	18.8	0.114
3/8-in. 5083 Al, horizontal lap weld	Automatic	1	1/8-in., 5556	65	420 DCRP	23 1/2	5/16	3/8	3/8	34.0	0.050
3/8-in. 5083 Al, horizontal lap weld	Semiautomatic	1	3/32 in., 5556	60	325 DCRP	27 1/2–28 1/2	3/8	1/2	3/8	17.4	0.077
3/8-in. 5083 Al, horizontal tee fillet	Semiautomatic	1	3/32 in., 5556	60	325 DCRP	28	3/8	7/16	3/8	14.6	0.092
3/8-in. 5083 Al, horizontal lap weld[a]	Semiautomatic	1	1/16 in., 5556	60	255 DCRP	28 1/2–29	3/8	7/16	3/8	13.4	0.088
3/8-in. 5083 Al, horizontal tee fillet[a]	Semiautomatic	1	1/16 in., 5556	60	255 DCRP	28	3/8	3/8	3/8	12.2	0.098

[a] Note: The data for these welds made with 1/16 in. wire were included in this table for comparison with the results listed above that were obtained with larger wire sizes. These welds were made using motor generator power sources with either semiautomatic inert gas wire feeder and controls or converted submerged-arc automatic equipment.

for the various wires. Brush electronic records were used to observe the ease of starting and the voltage fluctuations during welding. Many variables were studied during these tests.

Sufficient motor-generator machines were available for the job. Therefore, the purchase of rectifier or constant potential power sources was not warranted unless absolutely necessary. The latter was verified by the tests, because no appreciable difference could be seen in the performance of the wire feed units with the three different power sources. Later, this was also proved by the performance in production. All generators to be used for aluminum welding were cleaned, overhauled and recalibrated. A suitable external solenoid contactor was installed in the secondary circuit. This contactor is actuated by a small 110-v a-c relay. When the trigger of the welding gun is depressed, the secondary contactor closes, and the open circuit voltage is established. When the wire is touched to the work, the open circuit voltage decreases, an arc is established, and the control operates the wire feed mechanism.

Already available 1200- and 1500-amp capacity motor-generator power supplies for submerged-arc welding were converted for inert gas welding. This was accomplished by the following changes: First, the power generators were split in order to provide the range of current desired. Next, the gear ratio of the wire feed system was changed in order to increase the wire feed rate. The knurled wire feed roll was replaced with a smooth roll, and a heavy-duty nozzle with a heavy-duty contact tube made from hexagonal tubing was adapted to the gear box. Moreover, a water and gas flow unit, actuated from the start button, was installed. Finally, a 22-in. reel with 28 lb aluminum coil capacity was installed.

This converted automatic welding unit was tested in much the same manner as the semiautomatic equipment previously described. Brush electronic recordings made of these welds indicated very little preference, in the starting or operating characteristics, for any one type of power source. Instantaneous starts were obtained every time without a single burn-back. In addition, the depth of penetration was as good as or better than with comparative processes. As a final check, butt-weld tensile specimens were made with satisfactory results.

The selection of equipment was based on a production rate of 16 cars per day and about 1000 men to do the job. The only $^1/_{16}$-in. wire used was for tack welding with 1-lb spools.

Welding Procedure

It was possible to develop an extremely stable arc by using a high current density and as low an arc voltage as practical. This procedure gave several additional advantages. The penetration was deeper and more consistent, and the short arc provided a better cleaning action at the root of the weld. Because of this cleaning action, very good fusion was obtained at the root with a minimum of porosity in the weld. An additional advantage of the steady arc became apparent while welding the beveled joints on the bolster. Any misalignment of the welding wire in the joint was immediately noticed by an erratic voltage and then corrected.

Absolutely no dirt or grease could be tolerated adjacent to the sheared edges. Therefore, suction cups were used during handling for shearing, forming and burning operations to prevent contamination. Occasional dirt or grease was removed by hand cleaning with a trichloroethane solution. Power brushing with stainless steel wire brushes was confined to bolster and crossbearer joints as well as to the end sheets and the side sheets at the locations of the extrusions. The extrusions were pushed through a double power brush arrangement which cleaned the edges for welding. Also, the locations of the hand welds on the crossbraces were brushed, and the welds were brushed between passes.

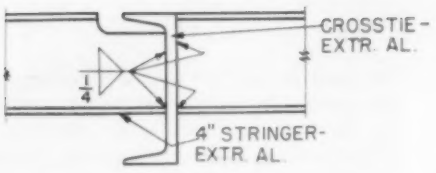
Allowance for shrinkage and camber proved a minor problem after construction was started, since the assemblies were flatter in most cases than their steel counterparts. Too much was allowed for shrinkage on the length of the side sheet, but this excess was easily trimmed off with a portable power saw.

Underframe Sub-Assemblies

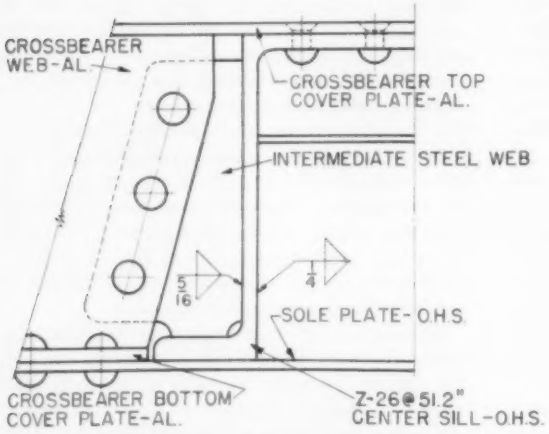
With one exception, all of the underframe subassemblies were constructed of aluminum. The exception was our standard arc-welded steel center sill with welded draft lugs and strikers. All of the attachments to the center sill were made by means of an intermediate steel plate riveted to the webs of the various aluminum sections and arc welded to the center sill web. Additional reinforcement was obtained by riveting the continuous top cover plates of the crossbearers and bolsters to the top of the center sill.

There are 10 crossties and 6 stringers per car to help support the floor. The stringers are longitudinal members (a modified 4-in. tee-bulb section) that are interrupted at each crossmember. Figure 4a, illustrates the cope in the stringer, which is required to clear the crosstie, and the $^1/_4$-in. fillet weld completely around the stringer for attachment of the two members. Intermittent fillet welds are used to weld the bulb portion of the stringer to the floor. The crosstie, also an aluminum extrusion, is a 6-in. channel section. The crosstie welding to the side sill, which is a part of the side assembly, is completed after the final assembly of these components.

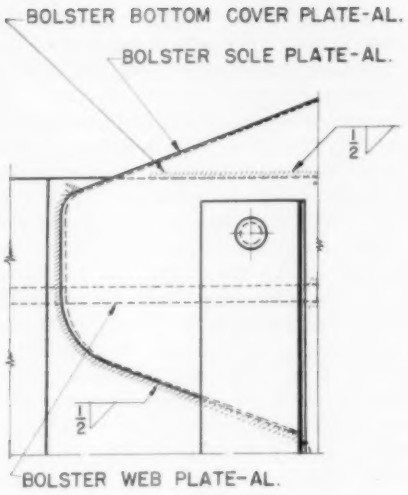
The crossbearers (8 per car) are aluminum I-beam sections, somewhat similar to the crossties in application, but much larger in section size. These subassemblies were constructed with a $^1/_2$-in. web plate automatically welded continuously on both sides, to $^1/_2$-in. top and bottom cover plates, with $^5/_{16}$-in. fillets. Figure 5 shows the automatic welding of a crossbearer subassembly. Also visible is the intermediate steel plate riveted to the aluminum



(a) Intersection of crosstie extrusion with longitudinal stringer extrusion



(b) Crossbearer connection to steel center sill. Typical steel intermediate web section rivets to web of crossbearer and then is welded to center sill



(c) Specially contoured aluminum sole plate welds to the bolster bottom cover plate

Fig. 4—Typical joints to be welded for the construction of the underframe

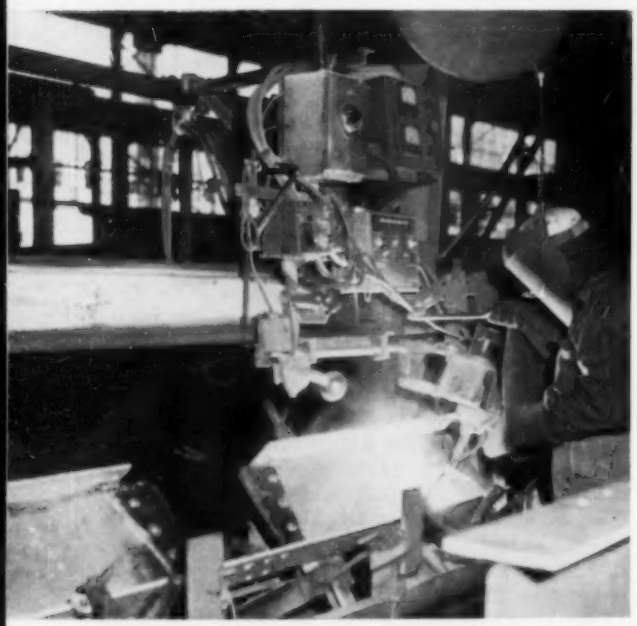


Fig. 5—The automatic welding of a crossbearer subassembly

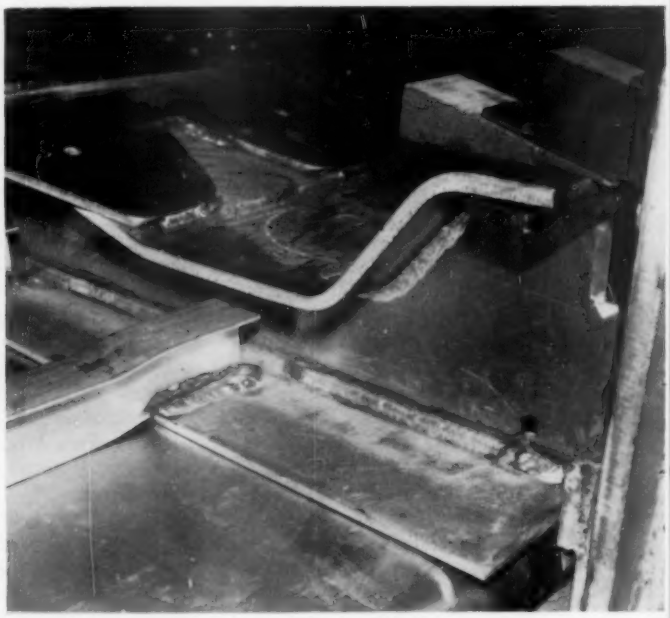


Fig. 6—The bolster subassembly, with the contoured bottom cover plate and sole plate, shown upside-down in the underframe assembly

web plates. The attachment to the center sill was by means of an intermediate steel plate as shown in Fig. 4b. In addition, a $^5/_8$-in. mild steel sole plate was riveted to the bottom cover plate and fillet welded to the center sill flanges. In order to improve the fatigue and impact resistance of the connection, special precautions were taken to terminate these welds back of any plate edges.

The bolsters (2 per car), which transmit the load from the car body to the wheel trucks, are of a box

section design, with thicker plates and larger sections, but still very similar to the crossbearer in the method of attachment. In Fig. 6, the bolster subassembly is upside down in the underframe assembly. In order to obtain sufficient wheel clearance, the bottom edges of the $^{5}/_{8}$-in. web plates were contoured by gas tungsten arc cutting. These contoured edges of the web plates were welded on both sides by hand to the $^{3}/_{4}$-in. bottom cover plate with $^{3}/_{8}$-in. fillets. While attaching the $^{1}/_{2}$-in. top cover plates, the inside web welds were inaccessible. Therefore, the remaining edges of the web plates were beveled, and automatically positioned welds were used for the top cover plate in order to obtain complete penetration. The top cover plate and bolster webs were also beveled in the same manner for welding to the side sheet and side sill angle.

As mentioned before, the bolster top cover plate was continuous for the width of the car and riveted to the center sill. For additional shear strength, a contoured $^{1}/_{2}$-in. mild steel plate was welded on the center sill adjacent to and tightly butted against each edge of the top cover plate. This addition provided the appearance of a tapered top cover plate. The $^{5}/_{8}$-in. sole plate, which in this case was aluminum, with a special tapered and contoured edge prepared by gas tungsten-arc cutting, is shown in Fig. 4c. This contoured edge of the sole plate was hand welded with $^{1}/_{2}$-in. fillets to the bottom cover plate, using the same precautions for weld terminations. The center portion of the sole plate was riveted, with the center plate, to the center sill.

The one-piece aluminum floor plate is an integral part of the underframe assembly, because all crossties, bolsters, etc., which contact the floor are welded to it with intermittent fillets. A 2-in. radius flange the full length of each side of the floor sheet was later welded to the sides during the final assembly.

Underframe Construction

The center sill and all the underframe subassemblies were fitted upside down on the floor plate in a large fixture as shown in Fig. 7. These included the sole plates and center plates, which were riveted to the center sill. The ends of the crossbearers and bolsters were located against large pedestals on the fixture which contained wedges for bringing these parts tightly against the floor plate. In addition, air hoses beneath the floor sheet provided uniform pressure over the entire area.

All of the welding at this location, as shown in Fig. 8, was accomplished with 26 semiautomatic inert gas metal-arc welding units. The "turtleback" wire feed units were suspended upside down on gantries directly overhead, and the 400-amp-capacity d-c motor generators were located on a platform above the work area. Two adjacent underframe fixtures were available. While one underframe was being assembled, the other was being welded, and the suspended wire feed units were pulled from one location to the other across the gantry.

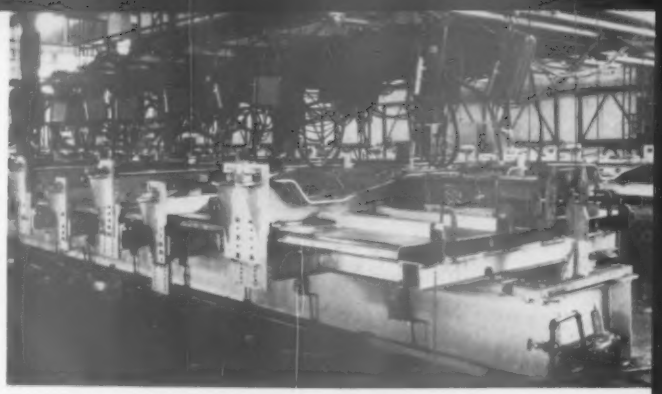


Fig. 7—The large fixture used for locating and clamping the underframe subassemblies to the floor plate

Fig. 8—Welding the various underframe components together

Fig. 9—Underframe positioned to permit horizontal welding

All of the members which contact the floor were welded at these locating fixtures. These welds were $^{1}/_{4}$-, $^{5}/_{16}$- and $^{3}/_{8}$-in. intermittent fillets made in one pass in a horizontal position. The three-pass horizontal fillets, between the bolster sole plates and bottom cover plates, were also completed here.

Then the underframes were rotated in the next positions in order to place the short fillet welds (between the longitudinal stringers and the cross members) in proper position for welding. Figure 9 is a view of the underframe positioned for welding. The top side is visible.

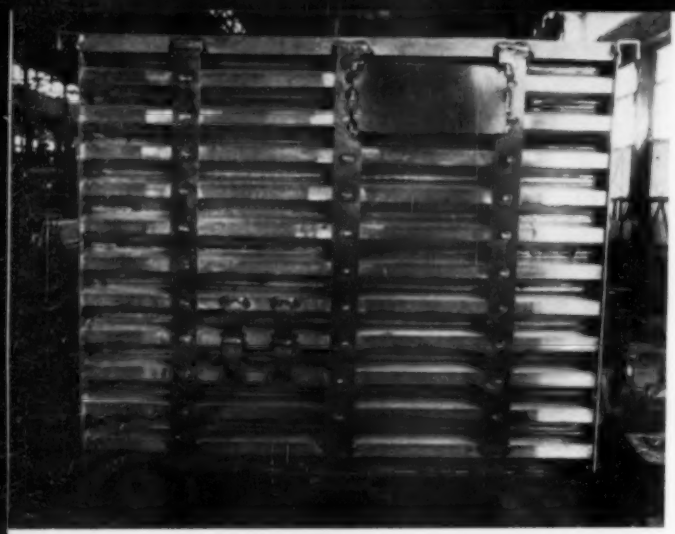


Fig. 10—The unique-design aluminum end, utilizing eleven hat section extrusions welded to the outside of the end sheet

Aluminum Ends

Description

The aluminum end shown in Fig. 10 is a unique design utilizing 11 hat section extrusions which run the full width of the outside of the end sheet. These hat sections are $^{5}/_{16}$-in. thick at the location of the welds and are spaced $^{5}/_{16}$ in. to permit sufficient penetration and width of fusion with automatic welding. Three $^{3}/_{8}$-in. thick, 6-in. wide vertical straps are slot welded to the top of the hat sections in order to increase the resistance to rotation. For added strength, the side sheets are extended sufficiently beyond the end sheet to permit welding around each hat section during assembly, producing completely enclosed box sections.

Figure 11a is a view of the hat section and end sheet weld, with the outside strap visible. A special U-shaped extrusion for the top end plate is also shown. This was butt welded to the extreme top hat section and joined with a $^{5}/_{16}$-in. lap weld to the end sheet. Figure 11b shows the bottom hat section and the end sheet welding to one leg of the $^{1}/_{2}$-in. thick extruded end sill angle. Both of the latter are $^{5}/_{16}$-in. lap welds. The other leg of the angle is welded at the heel and toe with $^{5}/_{16}$-in. fillets to the floor sheet.

Construction

The application of 13 complete and individual inert-arc welding units mounted on the same welding fixture was an outstanding example of automatic welding and fixturing. These were required to make the 11 butt welds and 2 lap welds on the end simultaneously.

Before welding the 11 continuous hat section extrusions, the top channel section and the bottom angle extrusions were tacked in proper location to the end sheet as shown in the lead photograph. In Fig. 12, part of the end welding fixture is shown with the welding in progress. Restraining clamps were used only at the extreme ends of the extrusions

(a) View of the top hat section extrusion which runs on the outside of the end sheet for the full width of the car. An extruded U-shaped top and plate laps the end sheet. One of three vertical straps which are slot welded to the hat sections is shown
(b) Bottom hat section and end sheet welding to the extruded end sill angle and welding of the angle to the floor sheet

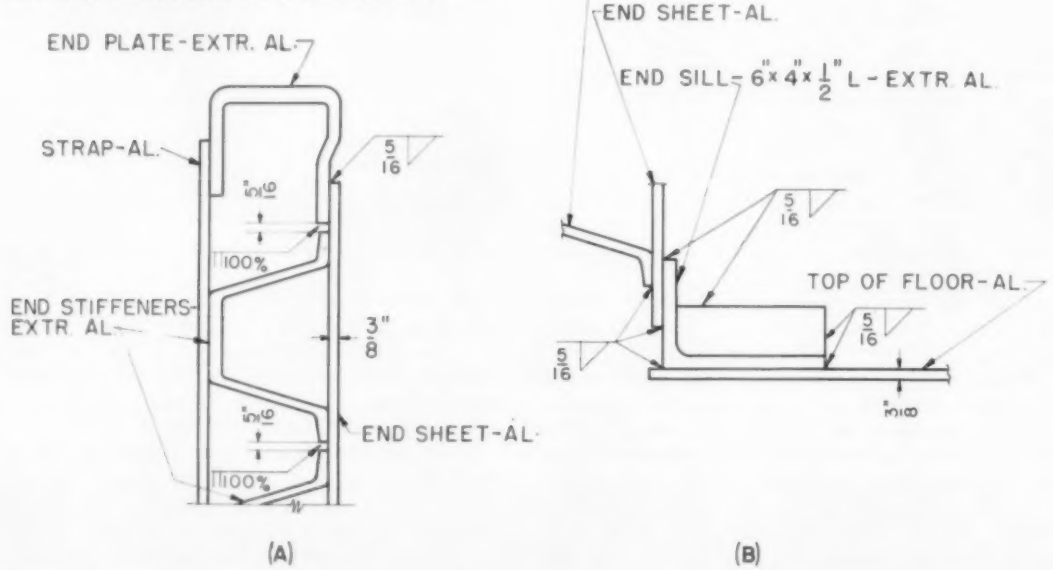


Fig. 11—Unique design of aluminum end subassembly

as the powered carriage traveled below the stationary welding heads. Considerable ingenuity was applied in the design of the machine just to find the space for the maze of nozzles, wire feed drives, argon and water lines, wire reels, etc. The shielding gas nozzles were inclined about 10 deg in the direction of travel and for the lap welds were, of course, inclined additionally in the other plane.

Only one major difficulty was encountered in the operation described above. Because the heat introduced and radiated was so intense, it was necessary to stagger the inert gas nozzles to keep from overheating them. Practically no arc blow was encountered with the unit just described, even with the 13 d-c welding arcs in such close proximity.

In the next operation, the tie straps were applied to the outside of the corrugations with slot welds. This straightened the slight bow which had been introduced by the welding of the hat sections without any camber. The end was turned over, and two automatic heads mounted on a gantry were used for the lap welds of the end sheet to the top channel and bottom angle. This completed the welding of the end assembly; a production rate of four per hour was attained.

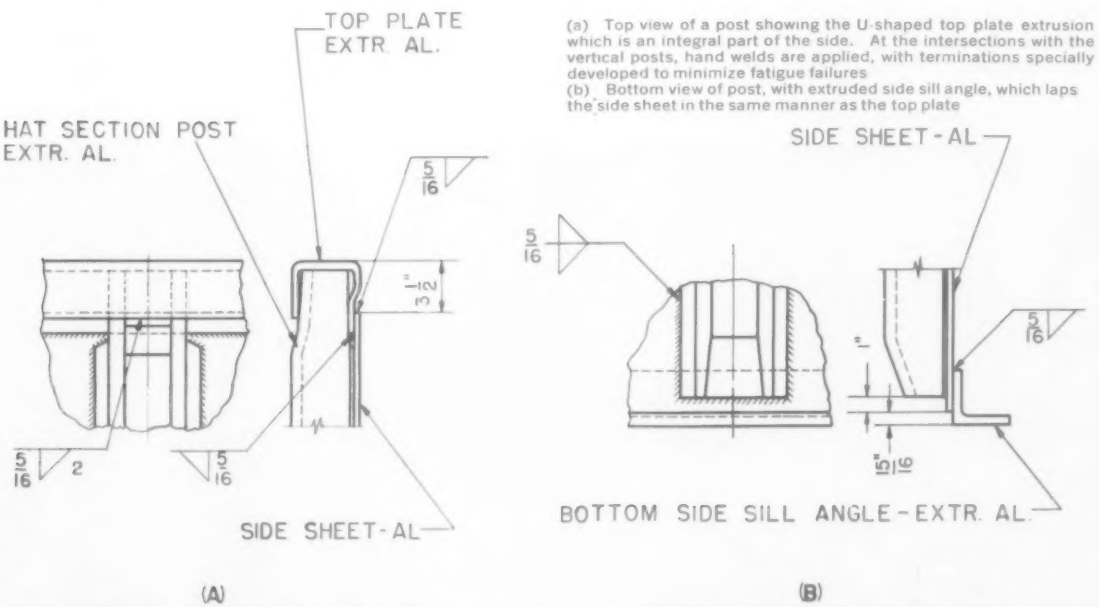
Fig. 12—Part of the end welding fixture with welding in progress

Aluminum Sides

Description

Except for the use of hat section extrusions for the posts, the design of the gondola side is very similar to that of a standard steel car. Eleven hat section extrusions are spaced vertically, approximately 4 ft apart, on the outside of the car. They are lap welded continuously and simultaneously on both edges with $^5/_{16}$-in. fillets to the side sheet. The outer enclosed leg of the hat section is extruded heavier in order to increase the strength without much additional increase in weight.

The top plate, an integral part of the side as shown in Fig. 13a, is a special U-shaped extrusion extending the length of the car. One leg, which is longer and offset to clear the side sheet, is automatically welded with $^5/_{16}$-in. continuous fillets on both sides of the sheet. Hand welds are applied at the intersections with the vertical hat section posts, with



(a) Top view of a post showing the U-shaped top plate extrusion which is an integral part of the side. At the intersections with the vertical posts, hand welds are applied, with terminations specially developed to minimize fatigue failures
(b) Bottom view of post, with extruded side sill angle, which laps the side sheet in the same manner as the top plate

Fig. 13—Design of the aluminum gondola side assembly is very similar to a standard steel car side. Heat section extrusions are used for the posts

Fig. 14—Automatic welding of the two longitudinal lap welds connecting the side sheet, top side plate and side sill angle

terminations specially developed to minimize fatigue failures.

The side sill angle, which attaches to the bottom of the side, is also a full-length extrusion. In a manner similar to the top plate, it laps the side sheet and is welded on both sides with $^{5}/_{16}$-in. continuous automatic fillet welds as shown in Fig. 13b. The side posts terminate short of this welding, and the automatic welds at these locations are tied in at the bottom with hand welds.

Construction

The first welds made were the two longitudinal lap welds on the outside of the car connecting the side sheet, top side plate and side sill angle, as shown in Fig. 14. For these first welds, the side sheet was assembled flat and horizontal and the parts were tack welded in place. Two individually powered gantries traveled on tracks adjacent to the fixture and straddled the side to be welded. Located on these gantries were two automatic inert gas welding units, which could be positioned independently. By following their own guide wheels, they made the $^{5}/_{16}$-in. lap welds.

The side was then moved on rollers to the next location. Here, by means of a clamping fixture, the 11 vertical hat section extrusions were located and welded. For this operation a total of three traveling gantries, welding simultaneously, were used. As shown in Fig. 15, these are located and locked in the proper position on the track for welding.

Each gantry has a pair of eccentric arms, operated by air cylinders, which locate and clamp each end of the hat section. Here, two automatic welding units, also individually and separately controlled, make the $^{5}/_{16}$-in. fillet welds on each side of the hat section simultaneously. A tension spring and guide wheel arrangement maintain the nozzle and wire of these units inclined at the proper angle to make these lap welds.

Adjacent to the track, d-c motor generators of 1200 amp capacity are permanently mounted on racks, and the power cables are carried above each gantry with sufficient slack to permit movement. This is a typical arrangement for the submerged-arc welding of steel hopper cars. The ground current is applied through a copper lug on one of the eccentric clamping devices, which grip the end of the hat section. The arc blow was much less than encountered previously with submerged-arc welding of steel. In order to weld steel satisfactorily, the polarities of the current on opposite sides were alternated.

The short hand welds shown in Fig. 16, which tie in both ends of the hat sections, were completed at the next location. Then the side was turned over for the final welding of the longitudinal lap welds at the top plate and bottom side sill. But for one exception, the fixturing and gantry arrangement for these automatic welds was very similar to that

Fig. 15—Three traveling gantries used to locate and weld simultaneously three of the eleven hat section posts on the side

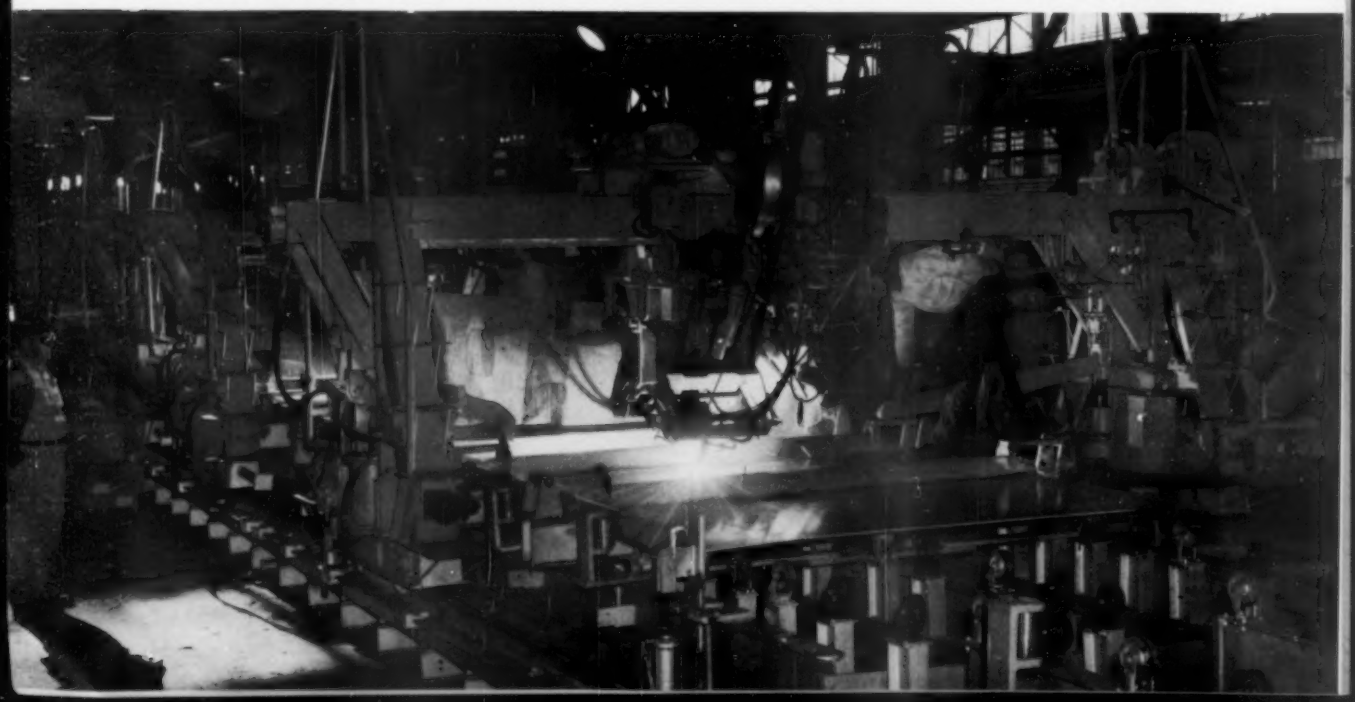


Fig. 16—Short hand welds were used to tie in both ends of the hat sections on the side assembly

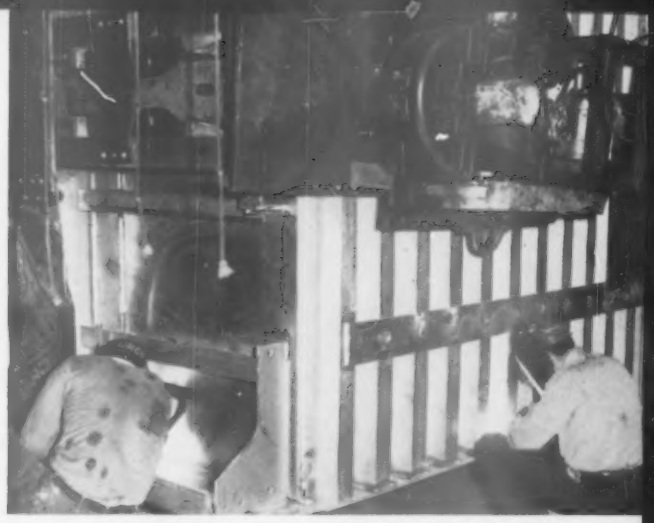


Fig. 17—Welding the end hat sections to the car sides in the final assembly welding at the roll-over positions

in the first position. The sill angle was not tight against the side sheet because the extrusion was not always square. For this reason, two automatic welding units with the wires spaced 20-in. apart and slightly out of line were used here to obtain a full $^{5}/_{16}$-in. weld.

Final Assembly

In the design of the car, the side sheets and the floor sheet extended past the ends. Nevertheless,

(A) Corner view of the method used to assemble the sides of the car to the ends. The side sheets extend past the ends; this permits welding around each hat section to make a completely enclosed end assembly. An extruded inside corner post angle is added for reinforcement

(B) Twelve diagonal side braces of 6" O.D. aluminum pipe are welded to the side and floor sheets. The contoured gusset shown here is welded to the pipe and floor

(C) The crossties, crossbearers and bolsters of the underframe are all welded to the side sheets and side sill angles. The crossbearer, a fabricated I-beam section, is shown here. The web is coped to eliminate intersections of welds in the corners

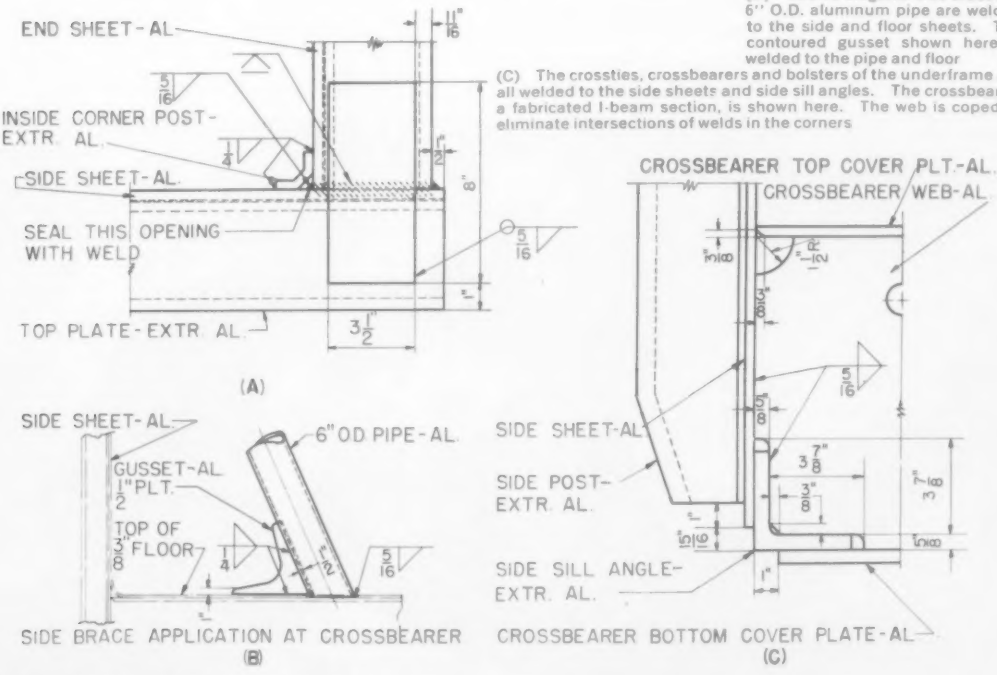


Fig. 18—Typical joints for the final assembly welding

Fig. 19—The car positioned on its side for welding the inside corner angle. The end sill angle, which is welded to the end and floor sheets, is vertical in this view

it was still more convenient to assemble the sides first to the underframe. The flat portion of the floor, which extended beyond the end subassembly required two continuous $^{5}/_{16}$-in. fillets to complete the welding to the end sill angle. In addition, as shown in Fig. 17, the end units were tied in completely to the sides by welding around each hat section on the outside of the car.

Also, $^{5}/_{16}$-in. fillet welds were used at the junction between the side sheets and the end sheets. In addition, as shown in Fig. 18A, a special extruded $^{3}/_{8}$-in. thick angle, with the heel removed to clear the corner weld, was added at each of these locations. Both legs of these angles were welded with $^{1}/_{4}$-in. fillets. Figure 19 is a good view of this operation. The car is positioned on its side for these welds, and the man in the lower location is welding the corner angle. The end sill angle, which welds to the end and floor sheets, is vertical in this view.

Finally, the $^{5}/_{16}$-in. continuous fillet weld between the side sheets and the 2-in. radius flanges on the floor completed the welding on the floor plate.

No particular problems were encountered in fitting the subassemblies for final welding. However, in order to help maintain alignment during welding, the diagonal side braces and transverse horizontal braces were applied as soon as practical. These braces interferred with any possible use of automatic welding on the floor. Therefore, all the final assembly welds were made at the roll-over locations where they were properly positioned for welding.

Figure 20 shows the application of the 12 diagonal side braces, which were made of 6-in. OD 5083-H 112 aluminum alloy Schedule 40 pipe. Gussets, with contours designed to eliminate possible stress raisers, were installed at each pipe location. They

Fig. 20—Application of the horizontal and diagonal side braces, showing the contoured gussets welded to the latter

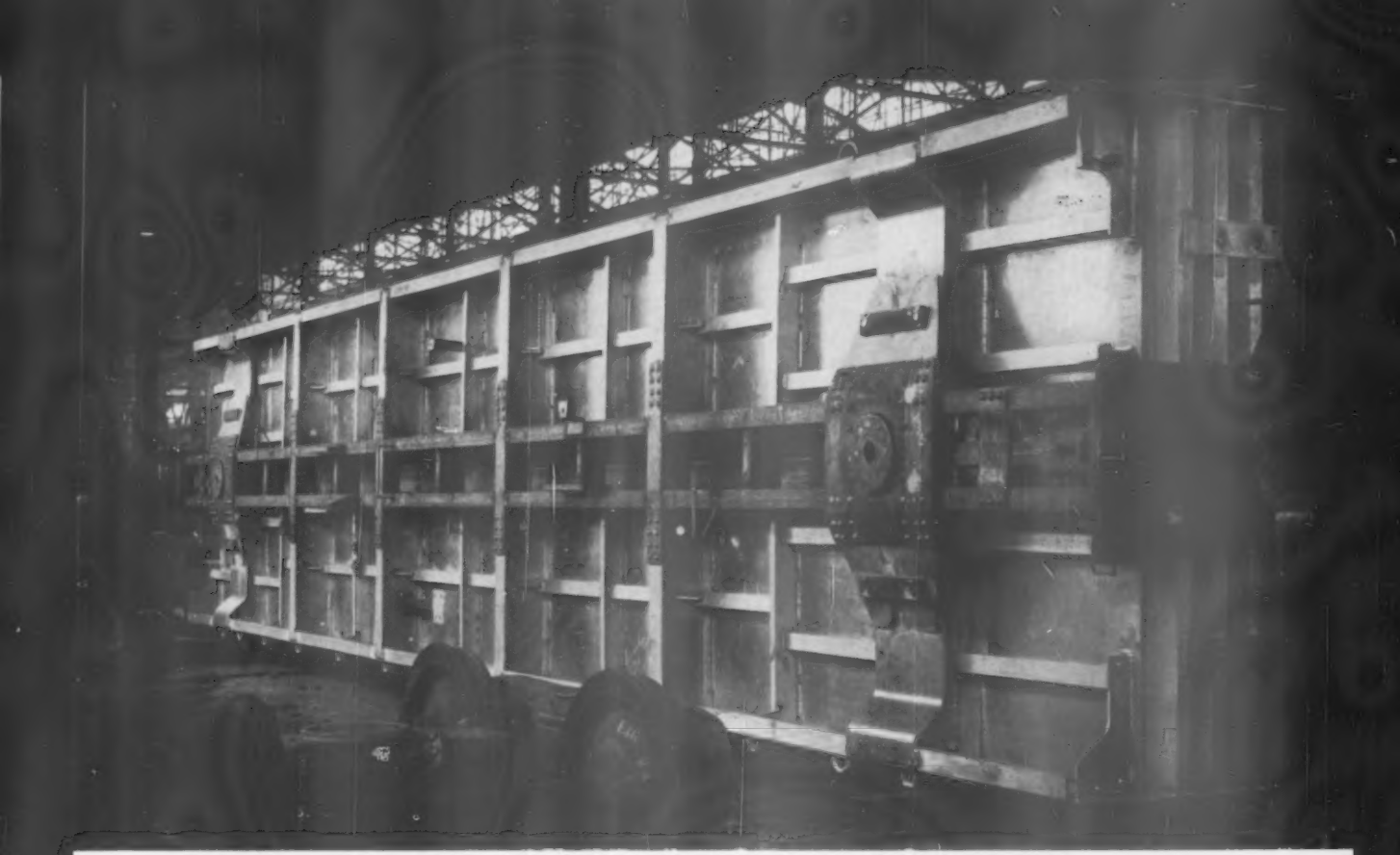


Fig. 21—Underframe of the completed car, illustrating the final welds between crossties, crossbearers and bolsters to the side sheets and side sill angles

were welded to the side and floor sheets.

Figure 18B shows the details of the contoured gusset weld to the pipe and the continuous weld to the floor. Five horizontal side braces, also shown in Fig. 20, are made of the same aluminum pipe and are centered between the diagonal braces. At each side, to facilitate removal, these were bolted to aluminum extrusions, which in turn were welded to the side sheets at the post locations.

There was, of course, considerable additional welding which was completed at the roll-over positions. For example, the crossties, crossbearers, and bolsters were welded to the side sheets and side sill angles. A typical application of this welding is illustrated in Fig. 18C. Here, the crossbearer, a fabricated I-beam section, is welded completely around the web with $^{5}/_{16}$-in. fillets to the side sheet and side sill angle. The web of the crossbearer is coped to clear the side sill angle. The latter then laps the bottom cover plate and is welded with fillets at this location. The web is also coped at the upper corner with a 1 $^{1}/_{2}$-in. radius to permit welding the top cover plate, which is inaccessible from above. Then, in order to provide sufficient attachment, the top cover plate is beveled $^{3}/_{8}$-by $^{3}/_{8}$-in. for welding to the side sheet.

This final welding is also well illustrated in Fig. 21, which is a good view of the underframe of the completed car.

Summary

How much can be said about the applicability of welded aluminum railroad cars from the results reviewed here? This much is known: The results of inspection, after a limited period of service, are favorable, and related applications, in dump truck bodies, for example, appear favorable. The 45% increase in pay load over an equivalent weight steel car is a real asset. Many railroads will watch with interest to see whether the Southern Railway System obtains lower maintenance costs and lower per mile operating costs.

From the results of the laboratory tests and experience gained in production, this much can be concluded: First, welded aluminum structures have become practical because of new welding techniques and the advent of high-strength cold-worked Al-Mg-Mn alloys. Higher joint efficiencies obtained with these alloys provide the designer a saving in material. Second, construction is simple because the use of full size aluminum sheets and extrusions simplify design and welding, and the production rate of 16 cars per day is easily attained. Third, hand welding operations were rapid, but the automatic welding required additional development in order to obtain speeds comparable with steel welding. Fourth, the lack of arc blow during the welding operation and the lack of appreciable distortion in the completed weldment are additional benefits.

Typical installation of silicon rectifier arc welding units. These incorporate all the forms of protection including thermal, inverse time-current overload and peak voltage suppression, and also the arc drive circuit

New fields in the design of power supplies are opened up when using

Silicon—The Key to a Reliable **Welding Power** Source

BY LEWIS F. PETTIT

Continuous research and refinement made the silicon d-c arc welding machine the most economical and reliable power source for welding operations. So unique and desirable are the characteristics of the silicon diode that their application to d-c welding units was anticipated by the welding industry long before their availability. Their high efficiency, absence of perceptible aging, ability to operate at high temperatures and their small size and weight are but a few of the many inherent advantages.

The Silicon Diode

The heart of the diode consists of a very thin wafer of pure silicon fused into a rectifying sandwich called a junction. This junction has the amazing capacity to allow large currents to flow with little restriction in one direction but to impede or block current which attempts to flow across the junction in the reverse direction. Such rectification, as it is called, occurs with almost immeasurable power losses which is evident by the low heating which occurs at the junction.

The combination of relatively low heating and small size allows the junction, or disk, to be housed in a small copper capsule which is hermetically sealed to prevent contamination. The base of the diode accomplishes two functions—electrical connection to one side of the rectifier junction (usually the cathode) and transfer of thermal losses. The other electrical connection is made either to a flexible lead or stud protruding from the top and joined internally to the junction.

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The output current from silicon diodes is limited by the temperature of the rectifying junction. This temperature depends on the heat losses within the junction and the temperature of the environment. The problem arises as to how to dissipate a certain amount of heat from the device within a limited temperature rise of the junction above ambient. The construction of the cell provides for mounting the cell on a copper or aluminum fin of rectangular section. Thus the generated heat is dissipated by direct radiation from the exposed surfaces of the diode case and by conduction to the fin where it is radiated into the atmosphere.

Welder Rectifier Bridge

In the d-c welding unit, the fins with diodes are assembled into a compact bridge assembly having a multiple of six cells for three-phase full wave rectification. When forced convection cooling is applied to rectifier assemblies, appreciable economies may be realized as a result of the increased current ratings allowed. Thus, with cells currently available only six cells are required for welding units of 400 amp rating. Since in d-c welding machines the rectifier has the lowest thermal storage capacity of any component, the cooling air is made to pass over the rectifier assembly prior to any of the other components.

Air distribution is also improved by careful

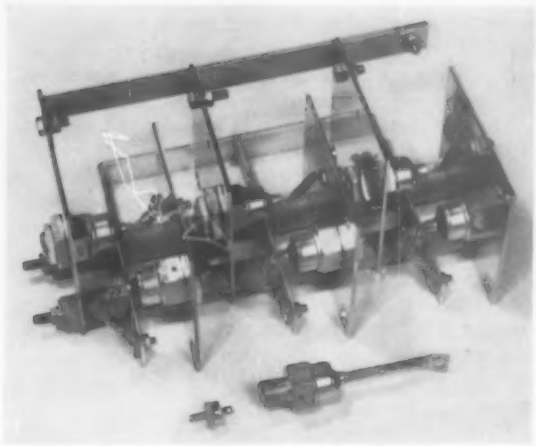


Fig. 1—A three-phase full-wave silicon bridge assembly used in a 300-amp welding power supply. In the foreground are a typical power diode and an arc drive diode. Diodes and radiating plates are generally nickel plated and the entire bridge assembly is built to withstand the rough service encountered in the welding field

baffling and by the use of shrouds. The ultimate test of cooling effectiveness is the actual junction temperature which can be determined from the measured case temperature and the thermal drop from junction to case. The maximum allowable continuous junction temperature is usually specified as 190° C (374° F).

Referring to Fig. 1, the rectifier cells including the mounting assembly are compactly and ruggedly built to withstand severe mechanical shocks. The cells and radiating plates are usually nickel plated and are highly resistant to moisture or corrosive conditions. These characteristics are of considerable importance in welding machines because of the rough usage and adverse atmospheric conditions normally encountered in the welding field.

Welding Characteristics

The practically negligible back leakage of the silicon cell, which along with the low forward drop contribute to amazingly high welding unit efficiencies (Figs. 2 and 3), also aids in improving welding performance. It is common knowledge that the reactor in a welding machine provides means for adjusting the output current and serves to limit the short circuit which may produce excessive spatter during welding. Another important function of the reactor is to store energy electrically which is essential to a stable arc. Whenever conditions in the arc tend to cause a momentary interruption of the current (arc outage), the stored energy of the reactor is instantly released. Such a transient surge of energy can be partially dissipated in back leakage of the rectifier, thus destroying its effectiveness in sustaining the arc and preventing current interruptions.

Silicon rectifiers having much lower leakage than selenium provide more efficient use of the reactor energy resulting in improved dynamic characteristics of the welding unit and a more stable arc even under adverse welding conditions. Conceivably, difficult-

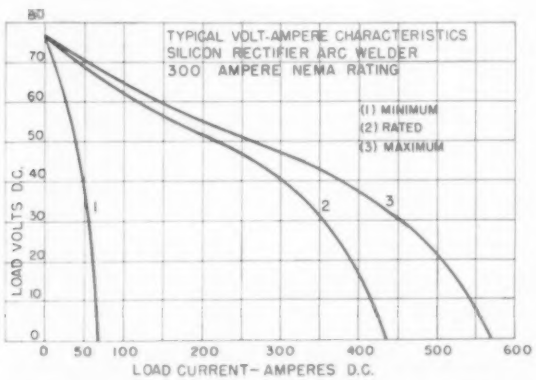
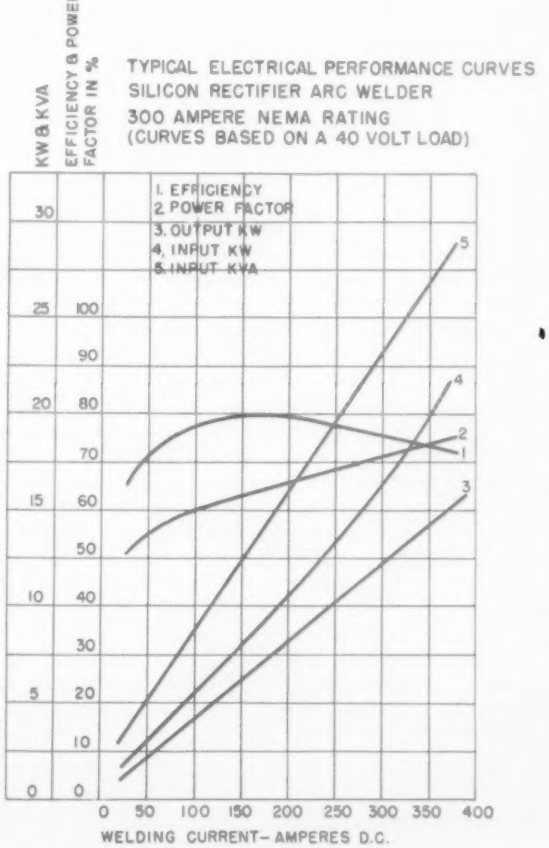


Fig. 2—Performance and volt-ampere curves of a 300-amp silicon rectifier unit. Volt-ampere curves are shown for minimum, rated and maximum current settings based on NEMA (National Electrical Manufacturers Association) standard limits. This type of welding power supply usually has a fixed open circuit secondary voltage. The drooping characteristic is adjustable to give different current settings. At any particular setting, the current remains relatively constant with change in load or arc voltages—referred to as a constant current machine. Performance curves are based on a 40-v load. Maximum efficiency of 80% is reached at approximately 50% of rated load



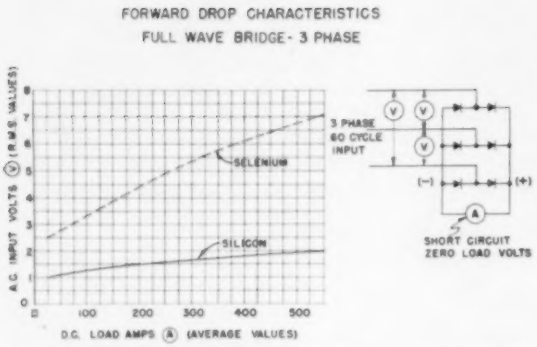


Fig. 3—Comparison of the forward drop characteristics of a three-phase full-wave silicon rectifier assembly vs. a similar selenium rectifier assembly. The simplified schematic on the right shows the meter connections for obtaining the volt-ampere data. In a silicon rectifier, the leakage current representing no-load loss is so small that it is practically insignificant. The over-all power loss of a silicon bridge assembly is approximately one-fourth that of a comparable selenium assembly resulting in much higher efficiency, improved voltage regulation and lower heating

to-weld material can be welded with improved results and less operator dexterity.

Peak Voltage Suppression

A phenomenon common to welding machine operation is that of transient surge voltages. The silicon diodes are subjected to all voltages of the circuit, both normal voltage and transients. Normal voltages can be predicted, but the transient voltage surges may appear from any of the following sources: transformer switching, release of magnetic energy stored in the leakage reactance of transformers and other system reactances following sudden interruption of load currents, or interruption of a-c loads operating from the same power source as the welder installation. Surge voltages as such are unavoidable. They are harmless only if they do not exceed the breakdown voltage of the diodes.

The complete suppression of all voltage transients is impractical and costly. As pointed out earlier, they are, in fact, a necessity in providing good arc stability, and complete suppression of voltage transients will result in poor arc starting and arc outages. If the peak voltage appearing on the diode can be cut down to a harmless value, the problem is solved. The common property of the various switching transients is that they contain relatively low energies but may include voltage spikes of sufficient magnitude to cause reverse failure of the silicon rectifying cells.

In the silicon welding power supply, the surge voltages are substantially reduced by the use of capacitors connected directly across the secondary terminals. The small amount of current drawn from the secondary will reduce the low energy transient voltages to less than twice the normal impressed voltage (operating peak). As capacitors can lead to oscillations and hence to other overvoltage conditions, their application must be checked carefully by oscilloscopic observations. For normal welding application in a three-phase bridge configuration, one small capacitor connected across the d-c terminal of the bridge is sufficient to prevent a dielectric breakdown of the diode by high voltage, low energy, voltage transients.

Failure Protection

Silicon rectifying diodes will short internally if a failure should occur from some cause such as overvoltage. In a rectifier bridge containing a number of diodes, i.e., six cells in a three-phase full-wave bridge, the failure of any one rectifier element entails an

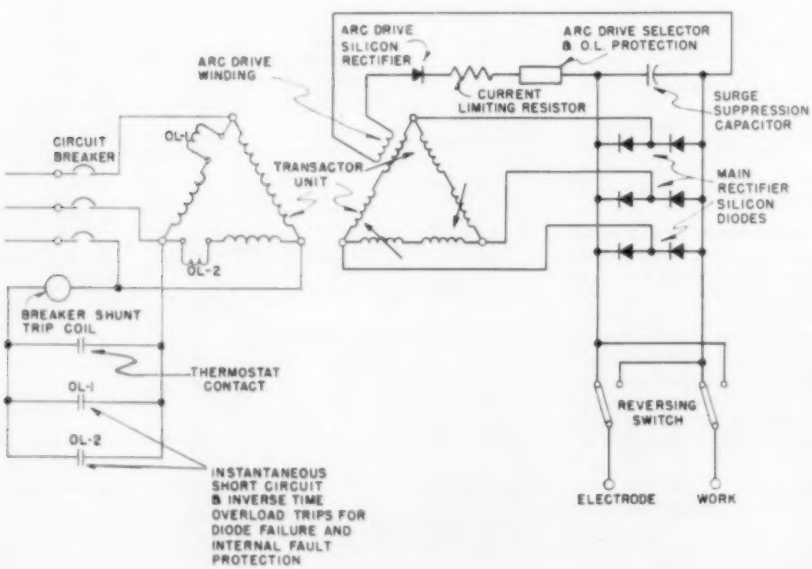


Fig. 4—A simplified schematic diagram of an all-silicon rectifier welding power supply incorporating various forms of protection including thermal, inverse time-current overload and peak voltage suppression, and also the arc drive circuit

internal short circuit of the unit which places a fault on the transformer and on other diodes feeding the fault. Thus a fault current flows from the good elements in the other two phases through the failed element in the third phase. This, in turn, results in a d-c component in the transformer secondary current which saturates the transformer core, thereby reducing the circuit impedance and causing an even higher primary line current. Without proper protection, either the transformer or associated wiring may fail or the high short circuit current flowing through the good cells in the other two phases will result in their eventual failure. The same is true for a diode failure in a single-phase full-wave bridge.

Adequate fusing affords some protection. In welding applications where the load current is adjustable and where proper operation depends on high transient current response, however, a fuse selected for protection at one load condition may not be adequate for another. A fast tripping circuit breaker which is magnetically tripped by the fault current through a relay or current transformer-relay arrangement has proved the most effective.

The relay is selected with inverse current-time characteristics such that a diode failure or other internal fault will cause instantaneous trip of the welder interrupting device but will not respond to ordinary current surges during welding—Fig. 4. Further, the relay current-time characteristics are coordinated with those of the rectifier diodes to provide fast relay response to abnormal load currents. Thus, unaffected by normal load currents, the relay scheme will respond to overload or fault conditions at a rate dependent on the seriousness of the condition. In addition, should the welding current or duty cycle rating be exceeded, a temperature-sensitive thermostat embedded in the transformer will respond to actuate the breaker and de-energize the welding unit in a like manner. Together, the thermostat-relay combination provides adequate protection for internal fault and overload conditions.

High Current Ratings

In cases where a number of diodes are used in parallel to obtain a high current rating, the problem of unequal current division is bound to occur because of the inherent disparity in forward drop characteristics of different diodes. This condition can be corrected by using matched diodes with identical forward drop characteristics, additional equalizing impedances, or by paralleling the rectifier bridges and supplying each bridge from a separate secondary winding. The use of matched diodes is impractical for procurement reasons. Likewise, balancing impedances added to the circuitry results in additional apparatus cost and power losses. Split windings supplying paralleled bridges has been proved to be most satisfactory for ratings where multiple operated diodes are required for higher current capacity.

Arc Drive

The desirable characteristics of the silicon diode have prompted its use in a number of auxiliary features which improve the performance of the rectifier type unit under unusual and often critical welding conditions. When welding by the "drag" technique using an electrode with drop transfer characteristics—for example—an instantaneous current overshoot is desired. The sudden increase in current has the effect of pinching off the globule of metal as it forms on the tip of the electrode and driving it forward, thus preventing the globule from bridging the arc gap and causing a momentary short circuit and perhaps extinction of the arc.

To provide for this condition, a separately excited low voltage d-c supply is connected in parallel with the main output to provide a momentary surge of current instantaneously when needed and just as quickly return to normal when the globule has been dispersed. The output current of this arc drive feature varies from zero at approximately 20 arc volts to a maximum peak current of 100 amp or more at short circuit—Fig. 5. This has the effect of increasing the maximum instantaneous short-circuit current without altering the static volt-ampere characteristics or increasing the heating effect of the arc.

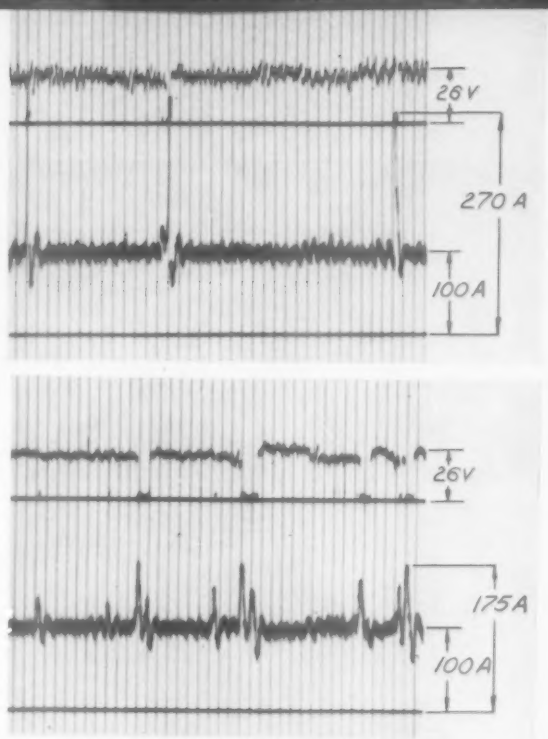


Fig. 5—Two oscillogram recordings, each with an arc voltage trace above and a current trace below. The solid horizontal lines represent zero voltage and zero current. The upper picture was recorded with the arc drive "on" and the lower picture is with the arc drive "off." Welds were made at a nominal current setting of 100 amp using a $^1/_8$-in. type 6010 electrode. The horizontal time scale is $^1/_{60}$ sec per division. The momentary current peaks (approximately 270 amp) provide a stable driving arc without increase in spatter or arc blow. Notice that with the arc drive "off" the fluid electrode metal bridging the arc gap causes the arc voltage to drop and remain at zero potential for periods reaching approximately 0.02 seconds

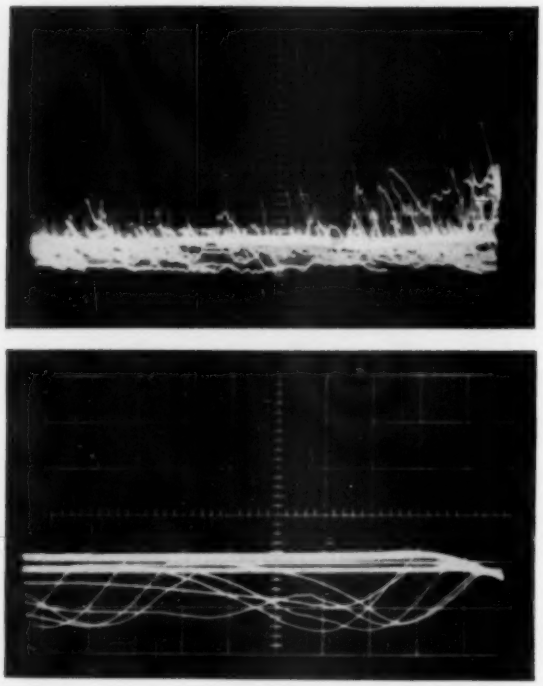


Fig. 6—Oscilloscope recordings made of the voltage appearing across the silicon rectifier under identical operating conditions while air carbon-arc gouging. The traces are recorded right to left. The scale is 50 v per division vertically and 0.5 millisec horizontally. This is equivalent to approximately $^{3}/_{100}$ of a cycle per division or a total trace time of only $^{3}/_{10}$ of a cycle. The top picture shows a series of repetitive traces with voltage peaks up to 200 v. The lower picture shows results obtained under identical conditions, but with the addition of a peak voltage surge suppressor. Here voltage peaks have been limited to approximately 115 v

In addition to rectifying the auxiliary supply current, the diode serves to prevent power feedback from the main circuit. The auxiliary circuit is resistance limited giving an extremely low time constant and instantaneous response. Because of the extremely short duration of the current spikes, the heating effect of the arc drive current in the arc is negligible. This circuit is protected against abnormal conditions by a thermal trip in the selector breaker.

Air Carbon-arc

An interesting protective innovation is the voltage surge suppressor unit available as an auxiliary feature on welding units used with air carbon-arc cutting equipment. Gouging and metal removal service is a severe application for any type of arc welding unit. In this process, the arc is subject to frequent short circuiting and the current is repeatedly interrupted by the high velocity air jet which is constantly directed at the point of arcing to remove the molten metal. This arc interruption simulates the operation of a high-speed air-blast circuit breaker wherein air is employed to provide fast arc extinction between breaker contacts as the circuit is opened.

During air carbon-arc service, each high-speed interruption of the arc results in a sudden collapse of the magnetic field within the welding reactor inducing a relatively high, steep-wave, front-voltage spike across the rectifier. Within certain limitations, the faster the interruption, the higher the generated voltage spike. These surge voltages have been observed and measured on actual production applications using extremely accurate and reliable laboratory-type oscilloscope equipment—Fig. 6.

The criterion for judging the ability of a semiconductor device to withstand voltage surges is represented by the devices peak inverse voltage (PIV) rating. No risk of failure is involved as long as the PIV rating exceeds the peak transient surge voltage appearing across the rectifier junction.

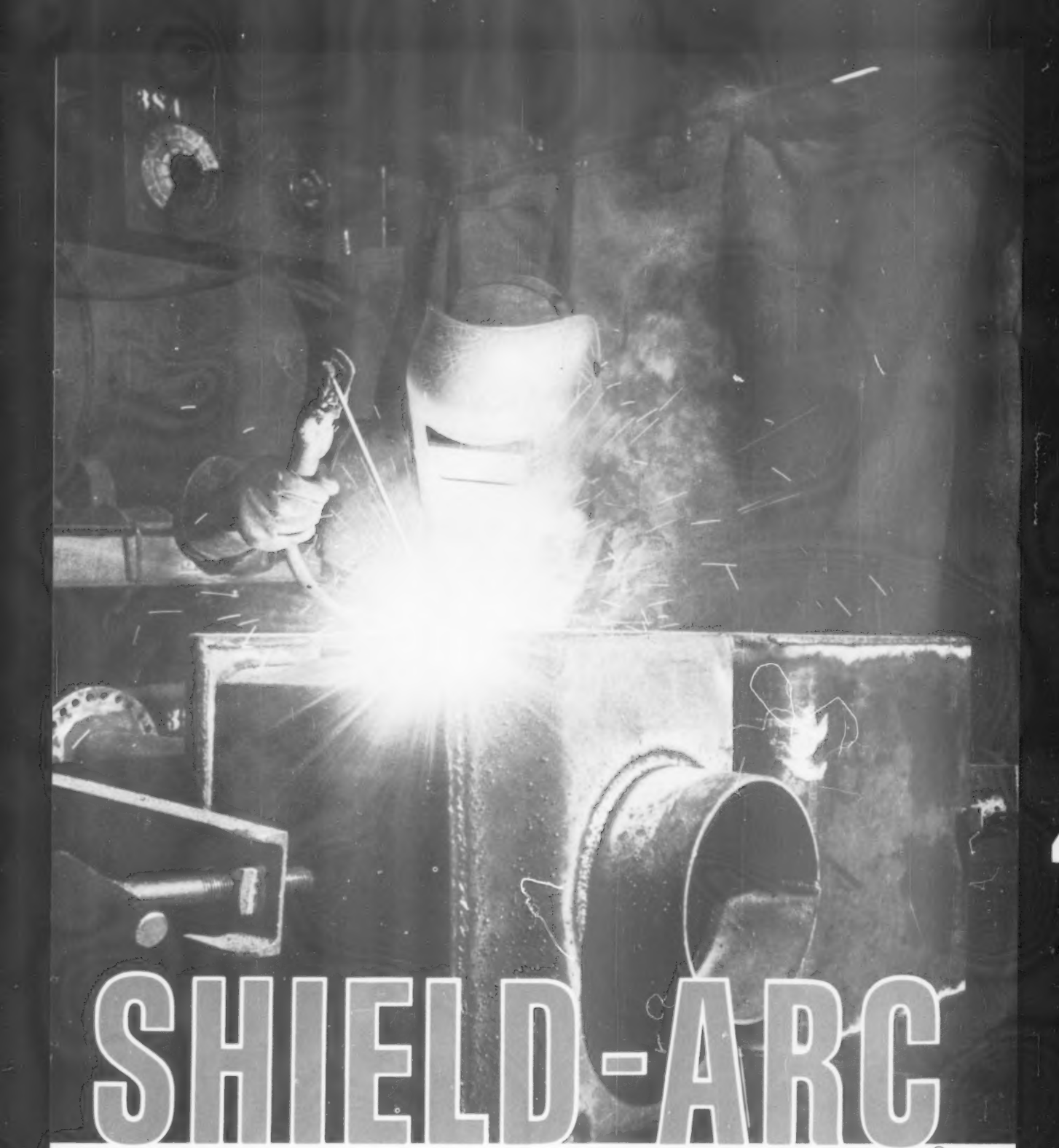
Selenium rectifier cells are limited to relatively low voltage ratings and on arc welding applications a multiple of selenium cells are connected in series to increase the voltage rating of the rectifier assembly. Even so, the transient peak voltage across the series string is not necessarily distributed equally across each cell due to variations in their reverse voltage characteristic.

Silicon diodes normally used in arc welding apparatus possess PIV ratings five or more times that of selenium cells. On the basis of two selenium cells connected in series, a common configuration for welder applications, the PIV rating of the silicon diode is a minimum of $2^{1}/_{2}$ to 3 times that of selenium. This inherent advantage provides silicon with a much greater operating margin between actual peak voltage and breakdown.

This safety margin is of even greater importance when considering the more severe conditions encountered with air carbon-arc service. By providing a reservoir to absorb and dissipate part of the transient energy associated with this process, the peak voltage appearing across the silicon junction can be reduced to values well within the limits of their capacity. Thus, a protective device can be built into the silicon welding machine to protect it against the severe conditions of air carbon-arc operation without adversely affecting the performance and efficiency on metallic arc welding.

Conclusion

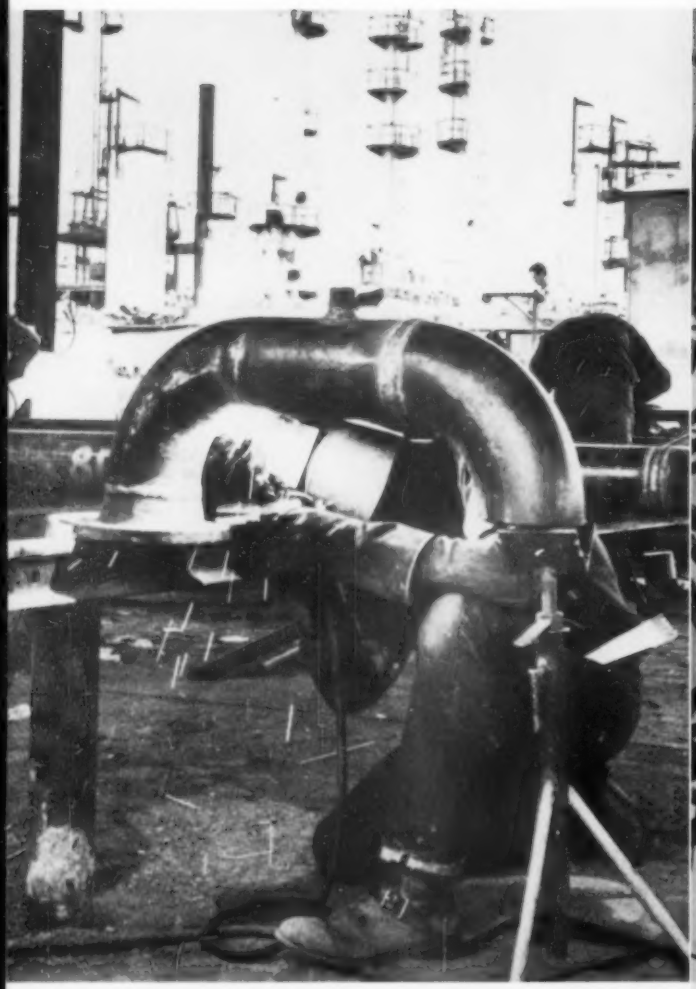
Silicon rectifiers have opened whole new fields in the design of welding power apparatus. Each application has its own particular design problems which must be carefully studied and analyzed to prevent indiscriminate use of a new device. Only through advancements, as such, in the design and development of new welding apparatus can the art of welding, in its many forms, keep abreast with the tremendous strides being made continuously in this technological era in which we now live. What the next ten years holds in store may well depend on the improvements being made this very moment in the field of metal joining.



SHIELD-ARC®

Lincoln **Shield-Arc** motor-generator welders are preferred 3 to 1 over any other kind of arc welder made. Why? Because through the years they have proved reliable, versatile and capable of producing consistently top-quality welds on all kinds of work — from heavy production to routine maintenance. On the following pages, we propose to substantiate these claims.

This is SHIELD-ARC on the job



Here, a **Shield-Arc** is used on a pipe fabricating job. But, any maintenance job which can be performed by manual welding can be performed best with these machines. Their wide range of currents lets you handle sheet one minute, heavy plate the next, stainless steel the next. In every case you'll get easy, fast welding backed by a rugged, dependable machine.

Whether you use **Shield-Arc** motor-generators in the shop or **Shield-Arc** engine welders on outdoor construction work like this, you'll find their design adds to the versatility of manual welding by making every job go easier, faster. And, their use of conservative, oversize components lets you turn out more work, longer, without danger of burning up the machine. These are beefy machines for the really big, tough welding chores.

How can you prove the reliability of any machine? You can't with words, really. But you can look at the record. And the record for consistent, trouble-free performance for **Shield-Arc** seems impressive. Over 400,000 **Shield-Arc** motor-generator sets have been sold and better than 60,000 of them are over 20 years old. A surprising number of them are still going strong today. And, in spite of the many new processes available today, **Shield-Arc's** continue to be in ever greater demand.

Versatility? Dual Continuous Controls let the weldor pick from literally thousands of possible combinations—the precise heat and voltage to suit both his style as well as the necessary arc type and intensity demanded by the job. These controls eliminate the need for compromise settings, assure best results, highest quality . . . and ultimately, the most profits for you. Moreover, each size machine offers a wide current range . . . lets you switch from one kind of job to another . . . quickly. If the weld site is distant from the machine, a remote control device can be installed to let the operator alter the current settings from the point where he's working.

Frequently, with transformer-type machines, output current varies due to changing loads on the line. This can result in inconsistent, poor quality welds. Because **Shield-Arc's** are motor-generator machines, and are unaffected by line voltage variations, you simply don't have this problem. You get the same consistent results all day long, day after day, regardless of the number of machines tied into the line.

All Lincoln welders are built with generous, oversize components. **Shield-Arc's** even more so. This means you can run these babies longer and harder than most other types, even do heavy-duty jobs such as Arcair gouging which often overheats and burns up lesser machines.

It's likely that your shop has one or more **Shield-Arc's** in operation now. You know from experience how they perform. But, if you do not, and if you want all these things from your welders . . . dependability, versatility, performance . . . don't take our word for it. Investigate for yourself the benefits offered by **Shield-Arc's** . . . today.

Why do you see more **Shield-Arc's** employed in heavy-duty, continuous production work like this? It's simple. These machines are designed—both electrically and mechanically—to continue to deliver heat at top efficiency as long as it's needed. Each component—from the generously oversized copper windings to the extra-large shaft and heavy-duty ball bearings—all combine to minimize the possibility of downtime, lost profits.

Shield-Arc's Dual Continuous Controls let the weldor select precisely the settings of current and voltage which suit both his style and what his experience tells him is best arc type and intensity for each kind of job. Thus, with a **Shield-Arc**, the weldor can produce the highest quality welds at lowest possible cost. These, of course, translate into higher profits for you.

Pick from several SHIELD-ARC models

Machine pictured is motor-generator model. Shield-Arc DC generators are available with AC motors, DC motors, gasoline engines, diesel engines, and as bare generators for belt driving. All are NEMA rated at 60% duty cycle, 40 volts. These are current ranges for the various sizes. Several types of running gear available.

Machine	Output Current Range Amps
SAE 200	40-300
SAE 300	60-450
SAE 400	80-600
SAE 600	120-750

WANT MORE INFORMATION ABOUT SHIELD-ARC's? See your local Lincoln field sales engineer . . . a specialist in welding. He'll help you pick the right machine for your job. Or, if you prefer, simply write direct to the factory for specification bulletins. All specifications, construction details and optional accessories are shown, described. Why wait? If you weld manually, check into the benefits Shield-Arc's can bring to you now.

THE LINCOLN ELECTRIC COMPANY

Department WW-19123 • Cleveland 17, Ohio

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT AND ELECTRODES

LINCOLN ...USA

Practical Welder and Designer

Flash Welding Beats Shipyard Problem

Where manual arc welding is called for in assembling complex shapes of forged high-strength alloy steel but the metallurgy of the part rules this out, flash welding may solve the problem. That is how an overseas shipyard recently got around a trouble spot in assembling forged turbine blades which had to be—but otherwise could not be—joined by arc welding.

In this instance, the forgings contained two outer and two inner stubs. Rotor assembly involved welding stubs on adjacent blades to give strength and stability, and part configuration dictated the use of manual arc welding. However, the alloy was not weldable using manual arc welding. On the other hand, as with many types of steel, the alloy was amenable to flash welding.

Engineers at the Kobe (Japan) Shipyard and Engine Works of the Mitsubishi Heavy Industries, Reorganized, Ltd., solved the problem by first flash welding a special alloy lashing wire to the blade stubs and then manually arc welding the lashing wires. To get over the weldability hurdle, an alloy was selected for the lashing wires which can be both flash and arc welded.

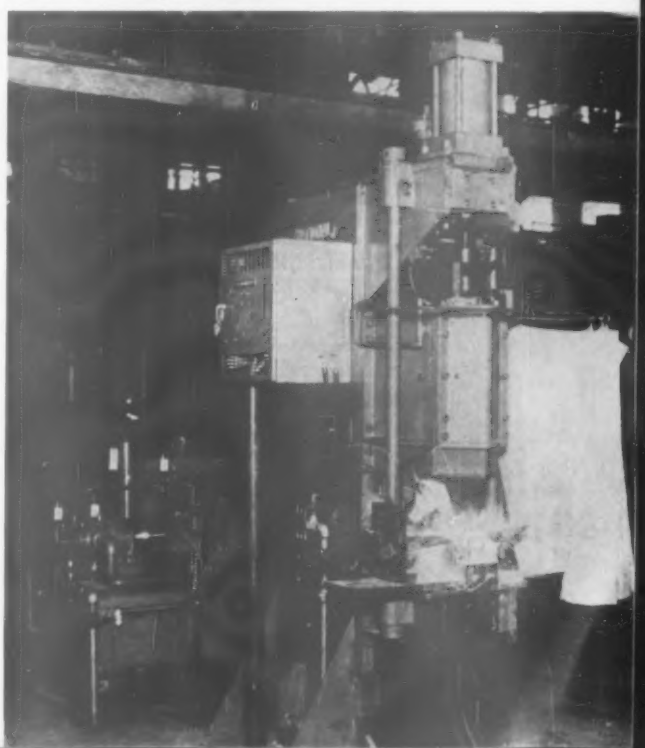
Part size and configuration also dictated the design of the heavy special semi-automatic flashwelder built for the job. Because the heavy blades, some as long as 54 in. and with compound contours, presented a loading and handling problem, the equipment was designed for welding in a vertical plane. The movable platen is at the top and moves down against the lower, fixed platen. Design involved a departure in this respect from the standard flash welder which operates in a horizontal plane. Thus the special welder for this application operates on a 19 sec cycle from manual load and clamping to manual unloading. Flashing and upsetting is automatic once the part is clamped in position.

The hydraulically operated unit welds one lashing wire at a time and is capable of welding stubs with a cross-section up to 0.75 sq in. Welding power is provided by a 100 kva, 220 volt, 60 cycle, single phase transformer with an eight-point tap switch heat regulator. The upper platen is controlled during the flashing and upsetting cycles by an hydraulic system capable of delivering 28,000 lb force. Current-carrying dies with quick-change inserts and blade locators are mounted on the lower fixed platen. Heavy-duty hydraulic clamps hold the blade on the dies. Unit clamping pressure is kept high to avoid burning caused by irregularities in the blade contour.

In operation, one size of lashing wire stubs are run through the welder at a time. Stubs are approximately $2^1/_2$ in. long to provide a holding surface during the weld cycle. Later the upset material is removed and the lashing wire is cut to required length for arc welding.

Changeover from one stub location and size to another is quickly accomplished by changing inserts on the clamps and both sets of dies.

Burnoff sparks fly as flash welding machine fuses a lashing wire stub to forged, contoured blade in subassembly operation at Kobe Shipyard & Engine Works; in final rotor assemby, stubs are manually arc welded



Based on a story from National Electric Welding Machines Co., Bay City, Mich.

Inner sphere, which had to be made perfectly round to within $+^{1}/_{4}$, $-^{1}/_{2}$ in. on its 11-ft diam as a vital first step in forming the structure, underwent 100% radiographic inspection of weld seams for soundness

Template Technique Solves Tricky Problem

What's the best way to drill hundreds of sets of large-diameter, close-tolerance holes into massive spherical weldments assembled to house electronic equipment in the Navy's latest attack submarines?

Each assembly consists essentially of a sphere-within-a-sphere: an 11-ft diam inner ball of armor plate, which is capped at either end by truncated support cones and girdled by a network of ribs, around which an outer, incomplete ball of 14-ft diam is built. A third cone perpendicular to the axis of the support cones, extends outward from the waist of the spheres.

The third cone connects with the inner hull of the submarine when the sphere assembly is installed, to provide access to electronic equipment housed within the inner sphere. The overall height of the assembly is 22 ft from tip to tip of the support cones.

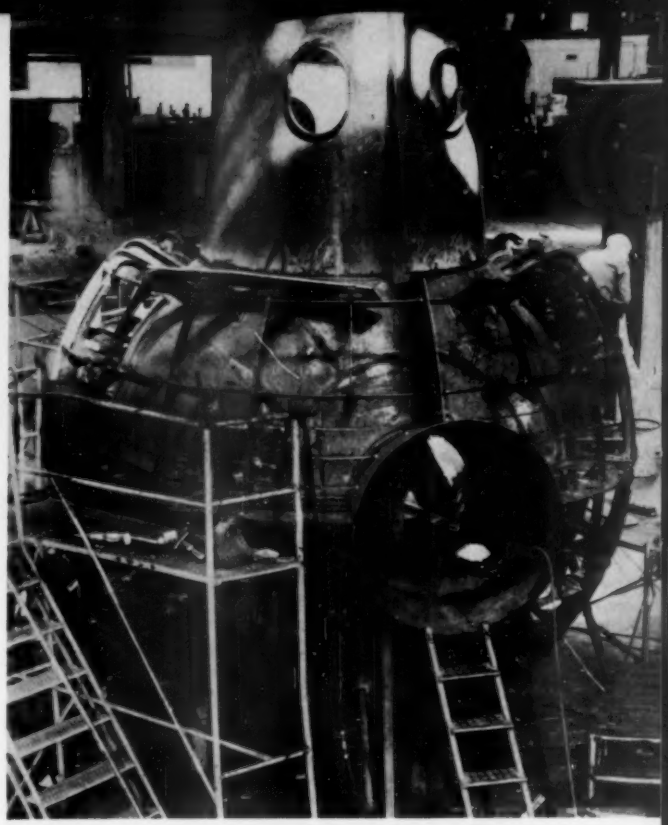
The drilling was the greatest single problem which had to be resolved in constructing four of the 22-ton assemblies. Other problems were: achieving the necessary sphericity of the inner and outer balls and establishing the concentricity of the two balls to the specified accuracy, by painstaking construction of the supporting rib framework.

Roundness the First Requirement

Getting the inner, foundation sphere round was the prerequisite to all of the other operations. This sphere was constructed of 12 "orange peel" sections of HY80 armor plate nearly 1 in. thick. These were press-formed, heat-treated for temper, and then restruck to a size tolerance of $+^{1}/_{8}$, -0 in. on a 68-in. outside spherical radius. Sections were assembled and tack-welded around barstock steel frames to form two hemispheres.

After the frames were removed, the hemispheres were joined, and all seams were completed by multiple-pass, electric arc welding. All of these welds had to pass 100 percent radiographic inspection for soundness.

Based on a story by Baldwin-Lima-Hamilton Corp., Philadelphia, Pa.



Here support cones, the entry cone and the rib structure around which the outer, incomplete sphere will be built, have been added to the inner sphere. Spacing between outer and inner spheres had to be held to 18 in., $\pm^{1}/_{32}$ in., to assure proper concentricity

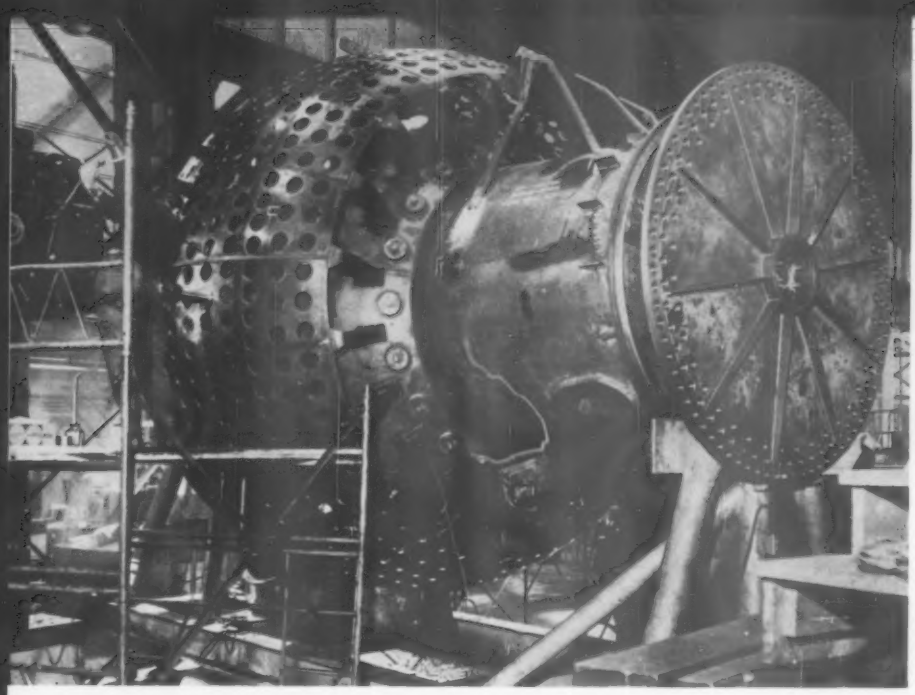
Separately fabricated support cones, the sphere entry cone, an inner-sphere floor and mounting ribs were then welded to this sphere. More than 50 different sizes and shapes of rib segments were used in weld-assembling five horizontal and 19 vertical ribs to the ball. These ribs had to be spaced to an accuracy of ± 1 deg, and the radial angle, at which they projected, had to be closely maintained.

These factors were vital to ensuring that the outer periphery of the rib structure was round and would hold the concentricity of inner and outer balls to within $^{1}/_{32}$ in. and to prevent the ribs being damaged during subsequent "blind" drilling operations.

Formed, orange peel sections of $^{1}/_{2}$-in. HT16113 steel were welded onto these ribs to form the outer sphere.

Ready for Critical Drilling Operation

Several factors contributed to the difficulty of machining the holes. Each sphere structure not only houses equipment, but becomes a functional part of the equipment. Because of this dual role, each set of holes (a set being an outer-sphere hole of one diameter and an inner-sphere hole of another) had to be spaced precisely according to coordinates on a



Sphere assembly is mounted on a cradle, which is in turn mounted on a turntable with vernier adjustment to position workpiece laterally under the drill head. Horizontal boring machine is at left. Template which positions assembly vertically is in foreground, mounted on the end of the support cone

standard, latitude/longitude chart supplied for the job. Each of the $5^1/_8$-in. diam outer-sphere holes became the center for four $^1/_4$-in. bolt holes spaced 5.375 in. apart, ±0.005 in.

These tolerances had to be held, and sufficient metal left between the larger holes and the $^1/_4$-in. holes to assure adequate ligament strength. Also, holes had to be drilled without cutting into weld seams in either sphere, without damaging any support ribs, and without cutting into any of more than 400 small "spuds" welded on the inside of the inner sphere, to support wiring and control cables.

Angle of entry was also important. Each set of holes had to be drilled on a centerline which, if projected along the axis of the drill, would intersect the geometrical center of the inner sphere. Maximum angular tolerance is 3 min. off true centerline, measured at surface of the inner sphere. It was decided that the best solution would be to rotate the workpiece in this instance, rather than the tooling. This would permit using standard horizontal-boring mills already at hand and avoid the cost and delay of special, elaborate movable tooling.

To rotate the workpiece, the vertical-mounting assembly was turned on its side and fitted with shaft ends which extended from the cones. Using these as trunnions, the shop suspended the entire assembly, now horizontal, on a cradle and mounted the cradle on a standard indexing table. This table had a vernier adjustment which permitted positioning the sphere surfaces very precisely under the stationary drill heads in the lateral plane.

A chain drive arrangement which coupled the trunnion to a drive motor mounted on the cradle rotated the assembly in a vertical plane past the drill heads.

Between them, these two positioning arrangements permitted full movement of the sphere assembly surfaces on both vertical and horizontal axes, without any shifting of the geometric center of the inner sphere which would throw the fixed drilling heads out of axial alignment with the center.

Template Guides Vertical Drilling

The problem of providing a precise means for vertical adjustment remained. While lateral adjustment of the sphere assembly, accomplished by positioning of the turntable, was required only once for each ring of holes drilled around the circumference of the spheres, the vertical adjustment was far more difficult. A fresh positioning adjustment had to be made for each hole drilled, and adjustment had to be held to within 0.002-in. tolerances.

An ingenious, 96 in. diam circular steel template was devised to accomplish this precise vertical positioning. The charted coordinates of the latitude/longitude chart were projected onto the steel plate, and holes corresponding to these coordinates were drilled in three concentric rings toward the outer edge of the template. The finished plate was mounted on the support cone of the assembly, on the end opposite the trunnion drive.

To position vertically, the operator had only to rotate the assembly on its "axle" until the desired template hold lined up with a master hole, put a pin into the lined-up holes, and proceed with his drilling.

This guide-template solution made precision drilling a simple and foolproof procedure. Quality control, was in effect, built into the template—and one or 100 spheres could be drilled to the same accuracy.

The horizontal boring mills, on each side of the assembly, drilled outer sphere holes first around each ring. A bushing was then fitted on each outer hole and the trepanning tool was moved in through the outer hole, which served to guide drilling of the inner hole, on the same centerline.

Drilling each sphere assembly by these methods took about three months—considerably faster, it is believed, than would have been possible by any other method.

Society News

Dallas Meeting Probes Space Age Problems

Technical Papers and Activities Evoke Unusual Interest in Fall Meeting Program

Dallas, deep in the heart of Texas, was host to AWS members, their friends and others who convened for four days at the Adolphus Hotel from Sept. 25 to 28, 1961. At the meeting emphasis was centered primarily on the technical program which saw the presentation of approximately 50 papers ranging from discussions on the welded repair of oil refinery equipment to a thorough exploration of welding problems encountered in the Space Age. Other events which contributed so much to making this a well-rounded meeting were a barbecue, plant tours and a full program for ladies. These activities coupled with the many committee meetings held throughout the week helped to make this meeting an unusual success.

Past President C. I. MacGuffie calls 1961 AWS National Fall Meeting to order at opening session

AWS President A. F. Chouinard presents welcoming address and predicts future growth for the welding industry

Attendees at opening session of the 1961 National Fall Meeting of AWS in Dallas, Tex., on Monday, September 25th

Much credit must be extended to the North Texas Section and its arrangements committee for the handling of the numerous details which were involved. Weeks of careful preparation and considerable behind-the-scenes activity were required to make this the smooth operation that it was. Theirs was an excellent job.

Past-President MacGuffie Opens Meeting

At precisely 10:00 a.m. on Monday morning, September 25, Past-president C. I. MacGuffie called the opening session to order. President A. F. Chouinard then addressed the meeting and predicted a two billion dollar market for welding equipment by the end of this decade. He concluded by stating that he could not "hope but see that we are at the beginning of a new era for welding, which is automatically a new era of service of our SOCIETY to the welding industry."

Following President Chouinard, three guests representing cooperating groups, extended their greetings to all present at the opening session. They were F. W. Davis of the Southwest Research Institute who spoke on behalf of the AEC Welding Forum, B. E. Justice from the Convair Division of General Dynamics Corp. who was present on behalf of the Society for Nondestructive Testing, and K. H. Koop-

F. W. Davis of the Southwest Research Institute addresses AWS members at the opening session on behalf of the AEC Welding Forum

B. E. Justice of the Convair Division of General Dynamics Corp. shown at the opening session where he extended the best wishes of the Society for Nondestructive Testing

K. H. Koopman as he spoke on behalf of the Welding Research Council at the opening session of the 1961 AWS National Fall Meeting

man who briefly described activities of the Welding Research Council.

Demoret Delivers Keynote Address

The keynote address at the opening session was delivered by R. B. Demoret, Chief of the Astronautics Section, The Martin Co., Denver, Col. Mr. Demoret, who is considered an outstanding authority on space vehicle design, chose for his title, "Space—Its Potential and Its Problems." In his address Mr. Demoret discussed the potentials of our space program and, in addition to military potentials, outlined expected benefits concerning weather control, medicine and ultimate commercial uses such as in television and hypersonic transportation. In discussing technical problems, Mr. Demoret stressed the role of welding with respect to booster fabrication as well as the fabrication of the space structure, itself. In his conclusions, Mr. Demoret expressed full confidence in the capability of this country to develop the full potentials of space and also expressed confidence in our ability to win the space race.

Technical Sessions

In keeping with the location of Dallas as a hub of activity in the aircraft, missile and space fields, many of the papers presented at the meeting discussed problems of related interest. One paper described the fabrication of a welded space cabin to withstand 1800° F re-entry temperature while other papers were concerned with items such as the fabrication of larger and more massive vehicles for space probes, the use of high strength steels in welded missiles, application of electron beam welding for joining metals such as titanium, and the welding of jet and rocket engine components.

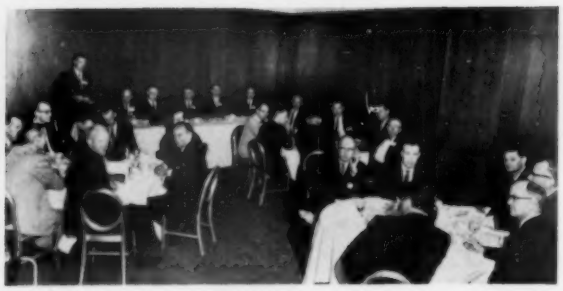
Keynote speaker, R. B. Demoret of the Martin Co., as he talked on "Space—Its Potential and Its Problems"

Another series of papers dealt with items such as the testing of welding titanium plates for submarine holes and the welding of units to convert sea water for use in nuclear submarines. Several papers were devoted to the welding of pipe while

AWS President A. F. Chouinard presents first Henry C. Neitzel National Membership Award to C. L. Moss, Director of District No. 9. Mr. Moss is accepting on behalf of the Shreveport Section

AWS President A. F. Chouinard presents another well-earned Henry C. Neitzel National Membership Award to A. W. Brown of the Detroit Section at the opening session of the 1961 National Fall Meeting at Dallas, Tex.

Miss Gay Sullivan of the Dallas Chamber of Commerce presents AWS President with a Texas Stetson hat while Mrs. Chouinard and Mr. Plummer look on. Channel 8 televised the ceremony and it was seen the same evening on the 10 o'clock news



T. P. Schoonmaker, Welding Journal Editor, reviews arrangements with authors and supervisors at the Author's Breakfast on Monday, September 25th. Seated at the head table (left to right) are: E. T. Mai, Secretary of the Arrangements Committee; R. A. Smith, Supervisor of the Opening Session; K. H. Koopman, Director of the Welding Research Council; A. F. Chouinard, AWS President, and F. L. Plummer, National Secretary of AWS

K. M. Spicer receives door prize between exhibition square dances at Western Extravaganza. Standing left to right behind Mr. Spicer are: National President A. F. Chouinard, Mrs. Chouinard who drew the winning ticket, Hospitality and Technical Chairman F. W. Salmons, and Barbecue Chairman J. R. Stewart

Some of the many AWS members and ladies who thoroughly enjoyed themselves at the Western Extravaganza. Food was served buffet style

Professor L. E. Wagner, University of Michigan, ponders answer to question from floor at Education Open Meeting

numerous other papers covered a diverse range of subjects such as new shielding gas techniques, the welding of earth moving equipment, maintenance welding for oil refineries and factors governing the selection of hose in oxygen cutting.

In addition to the many technical papers which were presented, a session of unusual interest was the Symposium on Fundamental Research. This was under the sponsorship of the Welding Research Council, and presiding officers were R. K. Grier of Allied Research Associates and Prof. C. M. Adams of the Massachusetts Institute of Technology. This was the first session of its kind and delved into the subjects of heat transfer intensity of electric arcs, transient heat flow and thermal stresses. Other sessions of noteworthy interest were sponsored by the AEC Welding Forum and the Society for Nondestructive Testing.

Committee Meetings

Beginning with Monday afternoon, several important AWS councils and committees held meetings to review work and to present recommendations relating to SOCIETY activities. These meetings began with a Section Officer's meeting at which AWS headquarters staff members described the activities of their departments and answered questions from the floor. Other meetings were held by the Missiles and Rockets Welded Fabrication Committee, the Publications and Promotions Council, and the Technical Council and the final meeting of the week was held by the AWS Board of Directors on Thursday morning, September 28. One unusual affair was an alumni dinner which was held on Wednesday evening, September 27, for former students from Ohio State University.

Educational Committee Activities

An Educational Open Meeting was held Tuesday afternoon, September 26. At this meeting, attendees were presented with a planning manual to help local section publicity officers in their work. Speakers included Dr. Merle Strong, Specialist Teaching Training and Service Studies, Trade and Industrial Branch, Department of Health, Education and Welfare, and Prof. L. E. Wagner from the University of Michigan. Professor Wagner discussed how best to present an educational course and the many steps and problems involved.

Associated with activities of the Education and Publicity Department were numerous interviews held by the press as well as by both radio and television stations with AWS members and others in attendance at the 1961 National Fall Meeting. In this respect, National President A. F. Chouinard was both heard on the radio and seen on television during the week of the meeting.

A. R. Lytle opens Symposium on Fundamental Research which was sponsored by the Welding Research Council

National Technical Secretary E. A. Fenton describes his activities at Section Officers Meeting. Seated behind Mr. Fenton from left to right are: Information—Education Secretary, A. L. Phillips, Past President, C. I. MacGuffie, Assistant Secretary, F. J. Mooney, and Journal editor, T. P. Schoonmaker

Fashion show which was held at the Neiman-Marcus in Dallas for the ladies of AWS members

Dato Stars at Extravaganza

A highlight of the meeting was a Western Extravaganza held at the Austin Patio Ranch outside Dallas. This served to replace the more formal dinners of other national meetings and proved to be a thoroughly enjoyable occasion for all AWS members, guests and ladies who attended. Food was served buffet style and was followed by an exhibition of square dancing under the guidance of a professional caller. At this point, J. E. Dato was called on to serve as caller and proved more than capable to the delight of all attending. As evening ended, it was impossible for at least two among those present to avoid the temptation of a well-lighted and beautiful swimming pool. Both displayed unusual form as they paddled up and down.

Informal bridge party for the ladies on Monday afternoon at the Hotel Adolphus in Dallas

Program for Ladies

A full program of social activities beginning with a coffee hour each morning kept the ladies pleasantly entertained during their stay. On Tuesday, the ladies toured the Amon Carter Museum of Western Art at Ft. Worth and returned to Dallas for luncheon at the Ports O'Call restaurant. The high point of all activities for the ladies was, however, a style show at the Neiman-Marcus on Wednesday. Following a tour of the wholesale Decorative Center in Dallas that morning, the ladies enjoyed lunching at the Statler Hilton Hotel before proceeding to the Neiman-Marcus. Firsthand reports indicate that all styles displayed were gorgeous and "out of this world."

Plant Tours

Tours were arranged for AWS members on Wednesday, September 27, at the Convair Division of General Dynamics Corp. in Ft. Worth and at the Mayhew Machine Plant Division of Gardner-Denver in Dallas. At Convair, visitors were afforded an opportunity to see many facets involved in the manufacture of the first U. S. operational supersonic bomber—the B58. Of great interest were the various welding and brazing processes involved to meet the complex specifications encountered in this air frame. In addition, the uses of nondestructive test methods including radiography, fluoroscopy, ultrasonics, penetrants and eddy current equipment were highlighted. The fabrication of brazed stainless steel honeycomb

panels, numerical tape controlled milling and cutting, assembly and flight line operations proved of interest. At Gardner-Denver, visitors saw one of Texas' most diversified plants including all types of welding and machining. This plant fabricates numerous types of oil field and construction equipment starting with a low horsepower 100-ft drill to one having 2100 hp and capable of drilling 25,000 ft.

Boarding bus for plant tour at the Convair Division of General Dynamics Corp. in Fort Worth and the Mayhew Machine Plant Division of Gardner-Denver in Dallas

Opening Address

BY A. F. CHOUINARD

AWS President, 1961–62

I am pleased to have the honor of presiding at the Opening Session of this Fall Meeting of our SOCIETY, because this meeting ushers in the first year of what I consider to be a new era in the history of our SOCIETY.

Our prior years have been ones of real accomplishment, entailing hard work by many people, and we could not consider our future to be as bright as it is without these past accomplishments.

Our future is, of course, based upon that hard work, and I would like to review with you some of the high points of those years, and then have you look into the future with me to see why I consider us to be on the verge of a new era for our SOCIETY.

In the early days, we were forced to do a great deal by the cut-and-try method, simply because we knew no other way. But even as early as the 20's and the 30's we had reports in the WELDING JOURNAL of new ways of welding, and new ways of high-speed cutting that permitted us to shape our metals and provide considerable savings.

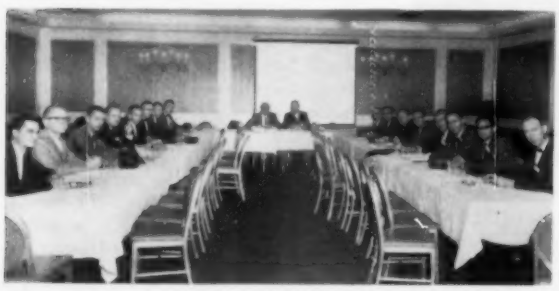
But these early years were not just years of struggle, because solid accomplishments were made. Welding had been accepted. It was used in the production of vacuum tubes, and railroad cars, and automobiles, and for many one-of-a-kind jobs, such as the turbines and the penstock tubing in the Hoover Dam. And one other giant step forward was the use of this process in putting up a building as early as 1930, when the Dallas Power and Light Building was erected.

After this came the war years, when welding really came into its own. Then in all of the years following the war, we have seen an unprecedented group of developments brought to maturity, such as gas tungsten- and metal-arc welding, new power sources and all of the gas-shielded processes, just to name a few.

I want to point out to you that none of these processes would have been brought to maturity without the work that our welding researchers did many years ago. Many of these processes used the methods and ideas that were proposed by the early workers in this field. It was simply necessary to wait for the development of one or two additional steps, and the process became a new way to weld.

During all of these years of technical growth in welding, we have had a paralleled growth of our SOCIETY itself. From its modest beginning we have seen many forward steps taken to improve its service to industry and to its membership. These changes have taken place in an orderly fashion over the past 15 years, but viewed from our position in 1961, they are considerable in number.

During this period we have expanded our technical and publication staff as the demand for technical literature on welding has increased. The SOCIETY took a far reaching step six years ago when the decision was made to publish the bible of our industry, the WELDING HANDBOOK, in five yearly issued sections. Welding Technology is moving so fast that this is the only convenient way to keep our HANDBOOK up to date. This is the year



Meeting of Missiles and Rockets Committee gets under way in Dallas

At luncheon just before the Meeting, the North Texas Arrangements Committee checked final details with AWS personnel. The group responsible for success of the affair included C. L. Moss, III, chairman; E. T. Mai, secretary and meeting sessions; J. R. Stewart, barbecue; F. W. Salmons, hospitality and technical; M. E. Eliot, ladies entertainment; W. H. Irwin, plant tours; and R. F. Skipwith, publicity

that our fifth and last Section of the Fourth Edition is to be issued and, as was planned, the next edition is to be published in a second cycle of five years, with each section newly revised.

We've done something to our SOCIETY's structure too, as you know. We streamlined it three years ago, patterning it after modern corporations so that our officers could function more effectively in their direction of our many activities. This has helped us in our growth, as it has permitted us to bring to other engineers the advantages of membership in the AWS through our Membership Activities Committee, and through our Education and Promotion Committees.

These advances have been made working under a balanced budget, and a budget that provided for all of these activities. It has permitted us to move into our new home in the United Engineering Center, and to furnish our quarters from our operating funds, and without touching our reserve funds. We should take pride that our Boards of Directors of the past few years have been so far-seeing that all of these steps have been so well planned that they could be executed in times like these.

But we have had other planners in the last ten years, those former officers who provided us with the means to hold our own sponsored Welding Expositions. Our first faltering step was the exposition held in Houston in May 1953. It was but four years later that our Welding Expositions became so large that we were forced to hold them only in the largest cities that could provide the necessary exhibit and hotel space.

And that brings me to this National Fall Meeting that we are officially opening this morning. The same thinking that provided for our own Welding Exposition has arranged these four-day meetings to provide both another technical forum and a means for our Section Officers to meet and discuss ways to promote welding in their Section activities.

AWS DIRECTORS-AT-LARGE

Term Expires	1962	1963	1964
	W. H. Hobart	R. B. McCauley	J. E. Dato
	F. G. Singleton	John Mikulak	A. N. Kugler
	C. B. Smith	E. F. Nippes	T. E. Jones
	J. R. Stitt	R. D. Stout	E. C. Miller

AWS DISTRICT DIRECTORS

District No. 1•New England	G. W. Kirkley	District No. 6•Central	R. H. Hoefler
District No. 2•Middle Eastern	C. L. Kreidler	District No. 7•West Central	L. L. Baugh
District No. 3•North Central	J. W. Kehoe	District No. 8•Midwest	G. O. Bland
District No. 4•Southeast	J. M. Shilstone	District No. 9•Southwest	C. L. Moss, III
District No. 5•East Central	P. J. Rieppel	District No. 10•Western	D. P. O'Connor
		District No. 11•Northwest	W. J. Ericksen

AWS PAST-PRESIDENT DIRECTORS

R. D. Thomas, Jr. C. I. MacGuffie

For it is a combination of our research in welding and our applications of welding that has permitted our welding industry to advance as it has. The financial people who predicted great things for the "Sizzling Sixties" have not been disappointed with the welding business despite the somewhat disappointing performance of industry in general. In 1960, which was a sluggish year for steel and some related industries, welding sales exceeded the previous year by some 75 million dollars, and it appears that this rate has continued into 1961. And 1959, you remember, was the first one billion dollar year for welding—a record set despite a prolonged steel strike.

Considering welding's present rate of growth and favorable forecasts for the economy in general, it's a good bet we'll see a two billion dollar market for welding equipment and supplies by the end of this decade. For comparison, remember it took more than 50 years to reach the one billion dollar mark.

From this quick review of some of the past accomplishments of both our SOCIETY and of our welding industry, coupled with the unlimited future that lies ahead, I hope that all of you will join with me in calling the years ahead the new era for our SOCIETY. We have new processes already waiting for unthought of uses, such as electron beam welding, friction welding and the further use of our present gas-shielded continuous electrode welding processes. And, in our SOCIETY, we have more people helping us publish much needed welding literature to spread the usefulness of welding in areas still untapped.

I cannot help but see that we are at the beginning of a new era for welding, which is automatically a new era of service of our SOCIETY to the welding industry.

I say again to you that I take great pride in being able to stand before you this morning and preside at this opening session of our 1961 National Fall Meeting.

I am certainly fortunate to be the president of a SOCIETY of growth.

Thank you for your attention.

Board of Directors Approves By-law Revisions

During 1959 the By-laws of the AMERICAN WELDING SOCIETY were modified and simplified. The new By-laws as approved by the Board of Directors and the Members of the SOCIETY were published in the May 1959 issue of the WELDING JOURNAL beginning on page 489. Since that time your Board of Directors has approved several changes recommended by the Constitution and By-laws Committee. In the following, the wording as approved in 1959 is shown first. The recommended revision is then

indicated with comments when appropriate.

It is suggested that all AWS Members review these suggested changes and keep your copy for future reference. At a later date you will receive a ballot. Your National Officers and Members of your Board of Directors recommend that you vote approval of these revisions.

Existing By-law (Excerpt)	*Recommended Revision*
ARTICLE I Membership	
Section 1 (c) 6 Life Members. A Life Member shall be one who has served as National President of the SOCIETY.	Add "or is exempt from the payment of further dues in accordance with Article II, Section 1 (d)." This allows the title "Life Member" to be applied to those exempt from dues payment under present rules.
Section 2 (a) Honorary Members . . . Honorary Members shall be elected at a regular meeting of the Board of Directors by the unanimous vote of the members present, except . . .	Change to "Honorary Members shall be elected by the unanimous vote of the members present at a regular meeting of the Board of Directors or of those returning a letter ballot prior to a specified date, except . . ." This will provide for action when no regular meeting is scheduled.
Section 2 (b) Life Members. Life Membership shall be automatically conferred upon a Member by virtue of his having served as National President of the SOCIETY.	Add "and by request upon those who have met the requirements of Article II, Section 1 (d)." This change conforms to that in Section 1 (c) 6.
Section 4 (d) Reinstatement. Any Member or Associate Member who has been dropped for nonpayment of dues shall be eligible for reinstatement only upon payment of a reinstatement fee and shall not be eligible for admission as a new Member.	Change to "Any Member or Associate Member who has been dropped for nonpayment of dues shall be eligible for reinstatement without the payment of an initiation fee."
ARTICLE II Dues, Fees and Refunds	
Section 1 (f) Reinstatement Fees. Any Member or Associate Member who has been dropped for nonpayment may be reinstated upon the payment of a reinstatement fee of $5.00.	Omit this Section to conform to change in Article I Section 4 (d).
Section 2 Refund to a Section. At the beginning of each fiscal year . . .	Change to "At the end of the first quarter of each fiscal year . . ." Required Section reports not available in time to comply with old rule.
ARTICLE III Organization	
Section 2 (c) District Nominations . . . The District Nominating Committee shall report to the National Secretary not later than the first day of November . . .	Change to "The District Nominating Committee shall report to the National Secretary not later than the fifteenth day of October" in order to conform to publishing schedule of WELDING JOURNAL.
ARTICLE IV National Officers, Their Qualifications and Duties	
Section 5 (a) Temporary By-law.	Omit since it no longer has significance.
Section 6 Past-presidents . . . with letter ballot approval . . .	Change to "in meeting or by letter ballot approval . . ."
ARTICLE V Management, Audit and Financial Responsibilities	
Section 7 (b) The Administrative Council. The following committees shall report to this Council: Admissions, Awards . . . Welder Registration and Certification . . .	Omit "Welder Registration and Certification" since no such committee is now active.
Section 8 (b) The Technical Council.	Omit "the WELDING JOURNAL."
Section 10 (b) The Publications and Promotions Council.	Add "the WELDING JOURNAL" since this committee now reports to this Council rather than to the Technical Council.

ARTICLE VI Nomination and Election of National Officers and Representatives	
Section 5 Tie Votes.	Change "Vice-president" to "Past-president" to correct error in present rules.
ARTICLE VII Meetings, Exhibits, Quorum and Fiscal Year	
Section 3 Organization of Annual and National Meetings . . . shall prepare a budget and submit it to the Finance and Executive Committee for approval. A copy of this budget shall be submitted to each member of the SOCIETY's Convention Committee for guidance.	Omit last sentence to conform with new recommended procedure.
Section 6 Exhibits . . . With the approval of the Board of Directors, the SOCIETY's Convention Committee, in cooperation with the Manufacturers' Committee, shall carry on negotiations for the Exhibit . . .	Change to "With the approval of the Board of Directors, the SOCIETY's Exposition Committee, in cooperation with the Convention Committee, shall carry on negotiations for the Exhibit . . ."
	Section 9 Letter Ballots (*Note:* This is recommended new Section.) Where letter ballots are authorized to approve an action in lieu of a vote at a meeting, the required vote of the group shall be determined by the number of ballots received within the specified date, which date shall not be less than three weeks from the date of mailing.
ARTICLE VIII Committees	
Section 1 National Nominating Committee.	Change "first day of November" to "fifteenth day of October" as in Article III Section 2 (c).
Section 2 Office Assignment Committee. The Office Assignment Committee shall consist of either five or six members made up of the Chairman of the National Nominating Committee as Chairman, the current Chairmen of the four Functional Councils; that is, the three current Vice-presidents, and the Past-president serving as Chairman of the Administrative Council (who may also be Chairman of the National Nominating Committee) and the President-elect . . .	Omit "of either five or six members made up." Editorial change.
Section 6 Standing and Special Committees.	In two places change "by letter ballot" to "in session or by letter ballot" to conform with recommended procedures of Board of Directors.

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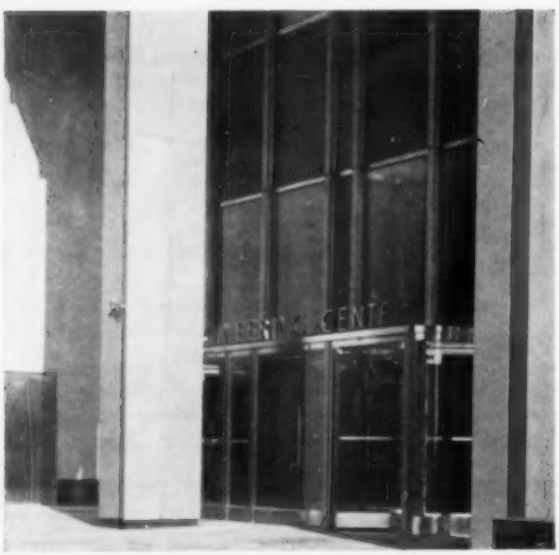
Light bounces off front of new UEC Building as sun rises in the east



Shadows highlight recently completed entrance to the UEC Building during the early part of the day

From Top to Bottom at Dawn

UNITED ENGINEERING CENTER

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	138	Niagara Frontier	107
New Jersey	133	Sangamon Valley	107
Louisville	130	Bridgeport	105
Mahoning Valley	121	Northwestern, Pa.	105
Kansas City	120	San Antonio	105
Worcester	120	Syracuse	105
Baton Rouge	119	Cincinnati	104
Birmingham	118	Providence	104
Northwest	117	Northern N. Y.	103
North Texas	115	Chicago	102
Hartford	114	N. E. Tennessee	102
Wichita	113	Puget Sound	102
Philadelphia	112	Saginaw Valley	102
Colorado	111	Tulsa	102
Detroit	111	San Diego	101
Albuquerque	110	Chattanooga	100
Dayton	110	Eastern Illinois	100
New Hampshire	110	Long Beach	100
Pascagoula	110	Los Angeles	100
Richmond	110	Madison-Beloit	100
Western Mass.	110	Michiana	100
Holston Valley	109	Mobile	100
New York	109	Nashville	100
Rochester	109	N. Central Ohio	100
St. Louis	109	Olean-Bradford	100
Boston	108	Pittsburgh	100
Long Island	108	Salt Lake City	100
Toledo	108	San Francisco	100
Iowa	107	Santa Clara Valley	100
Maryland	107	Stark Central	100

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Carolina	43	New Orleans	350
Anthony Wayne	150	Peoria	365
Shreveport	155	Susquehanna Valley	350
Iowa-Illinois	180	York-Central Pa.	375
Washington	180	Portland	385
Arizona	200	Houston	400
Nebraska	200	Sabine	400
J. A. K.	235	Lehigh Valley	415
Orange County	275	Fox Valley	450
Western Michigan	280	Columbus	770
Indiana	312	Milwaukee	832
South Florida	330	Cleveland	900

Pledges continue to move sections up the ladder to reach their goal. The majority of sections have attained 100% or more of their assigned quotas and have been placed on the Honor Roll. The last count shows AMERICAN WELDING SOCIETY pledges to be at 93% of goal.

KEEPING YOU POSTED

By Fred L. Plummer

● These notes are being written in New York just prior to departure for Dallas and the AWS National Fall Meeting. Ass't. Secretary Frank Mooney has left New York to discuss the formation of AWS Sections in the Borger, Tex., area on September 18th and the Odessa, Tex., area on September 20th, before arriving in Dallas on September 21st to complete final arrangements at the Hotel Adolphus for this meeting. Following this activity, he plans a vacation in Florida.

● Information and Education Secretary A. L. Phillips flies to Dallas on September 19th to handle early publicity, arrange for radio and TV programs, organize press interviews for principal speakers and national officers, and plan for other special educational and publicity activities. He will be followed by Ass't. Treasurer Ed Krisman (in charge of registration), JOURNAL Editor Ted Schoonmaker (in charge of program activities), Technical Secretary Ed Fenton and Ass't. Handbook Editor Bill Hall.

● The North Texas Section Arrangements Committee with Director C. L. Moss, III, as Chairman and Members Eliot, Irwin, Mai, Salmons, Skipwith and Stewart in charge of major activities, has completed plans and arrangements which will insure an outstanding meeting. When you read these notes, this meeting will be history—one of many such AWS meetings which have been outstanding successes; one of which President Chouinard, Convention Chairman MacGuffie and all AWS members may be very proud.

● Future AWS National Fall Meetings are scheduled as follows: 1962 Milwaukee, 1963 Boston and 1964 San Francisco.

● President A. F. Chouinard plans several AWS Section visits during November. He will present technical talks at meetings in cities and on dates as follows: Richmond, Va., 9; Birmingham, 14; Chattanooga, 15; Nashville, 16; Indianapolis, 17; Cincinnati, 21; and Buffalo, 30. Your Secretary will be in Europe during the first half of November, joining President Chouinard for the meetings in Cincinnati and Buffalo.

● Past-president C. I. MacGuffie and Vice-president C. E. Jackson met with your Secretary on August 23rd to plan meetings of the Districts Council and of Section Officers to be held during the National Fall Meeting in Dallas. Mr. Jackson left on August 29th for Australia where he was scheduled to address the members of the Australian Institute of Welding, present talks at several regional meetings and complete a tour of many of the industrial areas of that continent before returning to Honolulu to address the AWS Hawaii Section on September 29th.

● AWS National Headquarters were established in the new United Engineering Center early in September, the actual move taking place during the night of September 1st. Telegrams, flowers and other congratulatory messages were received from companies and individuals including President Chouinard and Exposition Manager Kenworthy. All departments were organized and handling normal activities on September 5th following the Labor Day holiday.

● Los Angeles Section Chairman A. L. Collin called on September 6th to confirm arrangements for a visit of your Secretary and President Chouinard on Feb. 15, 1962, to plan for presentation of an Adams Memorial Membership Award to Prof. Richard C. Wiley and to discuss a proposed paper for the 1962 Annual Meeting in Cleveland.

● Important conferences in your Secretary's office or by telephone during early September included those with President Chouinard, Past-presidents Hoglund and Thomas, Vice-president Blankenbuehler, Roger Clark, Bob Thornton who presented an invitation to attend the Annual Picnic and Field Day sponsored by the New Jersey Section and attended on September 16th by about 850 AWS members and guests, N. Adachi and S. Haraski of Hakusan Mfg. Co. of Tokyo.

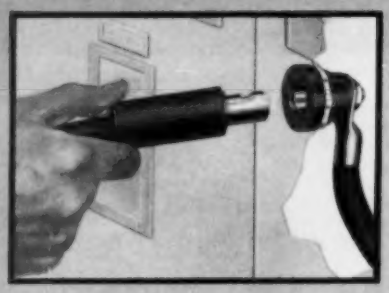
● The AWS Carolina Section organized a welding seminar held September 12–14th in Greensboro in conjunction with the 1961 Southeastern Plant Engineering and Maintenance Seminar.

● Chairman R. E. Somers and Secretary T. P. Schoonmaker conducted a meeting of the Technical Papers Committee held in the conference room in our new headquarters September 15th to select papers to be presented at the Annual Meeting in Cleveland, Apr. 9–13th, 1962. Eighteen members of this important committee, representing all segments of the welding industry and all areas of the country, participated in this meeting. Present plans provide for 24 technical sessions with some 72 papers. The Metals Division of ASME, the RWMA and the Cleveland Section of AWS will sponsor several of these technical sessions. The Society for Nondestructive Testing will hold its Annual Meeting in conjunction with the AWS Annual Meeting and will sponsor a complete technical program.

● The Eastern Zone Meeting of NWSA was held in New York September 18–19th with Vice-president D. C. Berner presiding and President W. P. McLendon giving a stirring address "Create a Challenge" after Executive Secretary R. C. Fernley presented a "Management Blueprint for Profit." The opening session included a "Buzz Session" based on a discussion of customer education programs by A. C. Earlbeck and concluded with a brief talk by your Secretary. A luncheon, reception and two additional sessions with important talks completed the two day program. Management methods, office automation, operation profit and an inspirational talk on creative thinking were included in the topics presented. A third day was devoted to a sales management seminar.

● The annual meetings of the Fabrication Division (A. R. Lytle, chairman), the Design Division (J. N. Downs, chairman), the Materials Division (N. G. Schreiner, chairman) and of the Executive and Main Committees (L. F. Kooistra, vice chairman) of the Pressure Vessel Research Committee of the Welding Research Council were held Sep-

Specify



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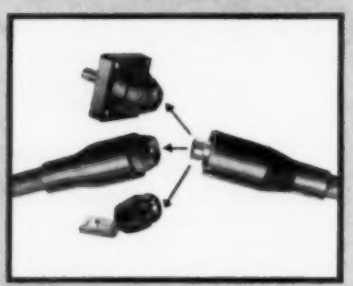
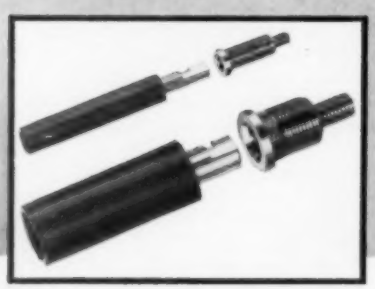
- MID-STATES
- BRENWELD
- BIRDSELL PRODS.
- HUGHES AIRCRAFT CO. (Vacuum Tube Products Div.)

. . . and many others





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For details, circle No. 9 on Reader Information Card

tember 19–21st in New York. C. F. Larson is Executive Secretary and I. E. Boberg Chairman of PVRC. K. H. Koopman is Director of WRC. At the meeting of the Main Committee J. L. Mershon presented an interium summary report on the results of the extensive research programs on reinforced openings in pipes and pressure vessels.

● Your Secretary attended a meeting of the Arc Welding Section of NEMA held at the Greater Pittsburgh Airport Hotel on September 21st, with Secretary R. L. Nims and Chairman Tom Berg in charge. Included on the agenda was an informative and interesting discussion covering the problem of foreign competition and how this affects welding business in this country.

● On September 28th the United Engineering Board of Trustees held a luncheon in the New United Engineering Center for Secretaries of the Founder and Associate Societies during which the lead cornerstone box removed from the old Engineering Societies Building was opened. Guests included President J. E. Johnson of the Carnegie Endowment for International Peace, a representative of the United Nations and several members of the press.

● Formal dedication of the United Engineering Center is scheduled for Nov. 9, 1961, with former President Herbert Hoover as Honorary Chairman, President Eric A. Walker of the Pennsylvania State University and other prominent individuals participating in the ceremonies. Officers and Directors of AWS will occupy honored positions.

● Elsewhere in this issue of the WELDING JOURNAL, you may read revisions in AWS By-laws which have been approved by your Board of Directors during the past two years. Please review these suggestions and be prepared to mark a ballot which you will receive late in December together with your annual ballot for officers and directors.

Plan Now to Attend
The AWS 43rd Annual
Meeting in Cleveland,
Ohio, April 9–13, 1962

For details, circle No. 10 on Reader Information Card→

World's largest steam surface condensers rely on M&T Murex electrodes

It takes huge condensers to handle over six million pounds of steam an hour. Right now Foster Wheeler Corporation is fabricating two of these giants for a large southern utility. Fully assembled, each weighs 800 tons, measures 82½ ft. long, 28 ft. wide, 43½ ft. high. Each unit has 300,000 sq. ft. of tube surface. In welding these twin record-breaking condensers, Foster Wheeler relied on M&T Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

EDUCATIONAL ACTIVITIES

AWS Fall Courses

The AWS School of Welding Technology is conducting two courses this month. The first is on Gas Shielded-Arc Welding and will be held Nov. 13–Nov. 17, 1961, at the Sheraton-Atlantic Hotel, Broadway at 34th St., New York, N. Y.

The second course will cover Testing and Inspection of Welds and will be held Nov. 27–Dec. 1, 1961, in the same hotel.

These courses offer the *only* opportunity for engineers, supervisors, inspectors, technicians and the like to be brought completely up-to-date on the latest welding processes and techniques in the short span of five days. The courses are designed as crash programs to cover thoroughly an entire subject in as short a time as possible. It is the only way industrial personnel can obtain this knowledge without spending weeks, and months attending engineering classes.

Furthermore, the faculty is chosen from the top people in industry—people who possess not only teaching ability beyond the average, but also the practical knowledge which comes from daily contact with manufacturing and production problems. From their own experience, these instructors can give examples which color and emphasize their talks. What is even more important, they are in a position to answer questions and solve problems which have puzzled both the students and their employers.

The comprehensive nature of these courses can be appreciated by the detailed course outlines which follow:

Gas Shielded-Arc Welding

1. Fundamentals
   - Welding Definitions
   - Metallurgy
   - Schematic of Processes
   - Welding of Noble Metals
   - Welding Equipment
   - The Arc
   - Shielding Gases
   - Base Metal Preparation
   - Joints
   - Welds
   - Positions
   - Inspection
   - Welding and Nondestructive Testing Symbols
   - Welding Codes
   - Welder and Welding Procedure Qualification
2. Gas Tungsten-Arc Welding (Part 1)
   - Definition
   - History
   - Essential Equipment
   - Arc Action
   - Characteristic Curves
   - Welding Technique
   - Shielding Gases
   - Process Selection
3. Gas Metal-Arc Welding (Part 1)
   - Definition
   - History
   - Essential Equipment
   - Characteristic Curves
   - Power Supplies
   - Shielding Gases
   - Reasons for Using Process
4. Gas Tungsten-Arc Welding (Part II)
   - Process Variations
   - Filler Metals
   - Base Metals
   - Factors Influencing Weld Quality
   - Gas Tungsten-Arc Cutting
5. Gas Metal-Arc Welding (Part II)
   - Process Variations
   - Filler Metals
   - Base Metals
   - Care of Gas Metal–Arc Welding Equipment
   - Safety
   - Costs of Welding
6. Gas Metal-Arc Welding–CO_2 Shielding Gas
   - Description of Processes
   - Equipment
   - CO_2 Supply
   - Filler Metals
   - Materials Welded
   - Process Characteristics
   - Safety
   - Spot Welding
   - Through Welding
   - Applications
   - Costs
   - Summary

The course on *Testing and Inspection of Welds* is equally comprehensive. The course covers:

1. Fundamentals of Testing and Inspection
   - Why Test and Inspect
   - Who Inspects
   - Inspection Methods Briefly Explained
   - Requirements for All Testing Procedures
   - Economics of Testing and Inspection
2. Selection of Testing Process

Please enroll me in the course(s) checked below. The registration fee is $75 per course. Check enclosed for the sum of _____.

Make checks payable to the American Welding Society, Inc.

Course enrollment list will be closed upon admission of 50 enrollees.

☐ Gas Shielded-Arc Welding Processes . . . held at the Sheraton-Atlantic Hotel, New York, N. Y., Nov. 13–17, 1961.

☐ Testing and Inspection of Welds . . . held at the Sheraton-Atlantic Hotel, New York, N. Y., Nov. 27–Dec. 1, 1961.

Hotel Reservation (if desired):

☐ Single Bedroom @ $10 ☐ Twin Bedroom @ $18

	Date	*Hour*	*Date*	*Hour*
Arrive:	_____	_____	_____	_____
Depart:	_____	_____	_____	_____

Name _____

Company _____

Address _____

City _____ State _____

For additional information write, wire or call Arthur L. Phillips, Secretary, Information and Education, American Welding Society, United Engineering Center, 345 E. 47th St., New York 17, N. Y.

For details, circle No. 11 on Reader Information Card——→

World's tallest structure relies on M&T Murex electrodes

Almost 1000 tons of steel stretching 1676 feet into the sky! This new television transmission tower for KFVS-TV, Cape Girardeau, Missouri, is the tallest structure man has ever built. It's 204 feet taller than the Empire State Building, has solid steel legs up to 7½" in diameter, can withstand winds of over 100 mph. In welding the 30-ft sections of this triangular tower of strength, Dresser-Ideco Company put its trust in M&T Murex electrodes... products of METAL & THERMIT CORPORATION, Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

- Type of Defects Found in Welds
- Codes, Standards and Specifications
- Selection of Inspection Procedure to Be Used

3. Testing Procedures I
   - Tension Tests
   - Hardness Tests
   - Torsion Tests
   - Miscellaneous Tests Applicable to Welds
4. Testing Procedures II
   - Fatigue Tests
   - Impact Tests
5. Nondestructive Testing of Weldments I
   - General Information
   - Types of Tests Briefly Explained
   - Selection of Appropriate Test
   - Determination of Acceptance Standards
   - References
   - Procedures Involved in Testing Methods
6. Nondestructive Testing of Weldments II
   - Visible Dye Penetrant Testing
   - Magnetic Particle Testing
   - Ultrasonic Testing
   - Magnetic Permeability Testing
   - Thermographic Inspection
   - Eddy Current Testing
   - Fluoroscopic Testing
   - Selection of Nondestructive Testing Methods
   - Determination of Acceptance Standards
   - References

The importance of these courses can hardly be overestimated. As Fred Plummer, AWS National Secretary, once pointed out: "United States and world industry will face increasingly competitive conditions during the next decade. Success, even survival, of individual companies and industries will depend more and more on their ability to develop new or improved products which can be produced with maximum economy. Welded fabrication will often be the key to success."

There are still vacancies in both courses. For convenience, an application blank has been provided on this page by which a place in the course may be assured, and hotel reservations obtained.

THERE GOES 30% MORE GAS

In the plant or on the truck . . . **you will move 30% more acetylene gas — if** the gas is in Coyne Acetylene Cylinders because there is a bonus of 30% extra gas capacity in **every** Coyne Cylinder. NOW is the time to increase your gas profits and decrease labor costs with this extra gas footage. Write or call for the facts on the complete line of Coyne extra capacity acetylene cylinders.

COYNE *cylinder company*
DIVISION OF AMERICAN CRYOGENICS, INC.
224 RYAN WAY, SO. SAN FRANCISCO, CALIFORNIA — PLAZA 6-6910
155 W. BODLEY AVE., MEMPHIS, TENNESSEE — WHITEHALL 6-7789
3600 SPRINGDALE AVE., GLENVIEW, ILLINOIS — PARK 4-3628

For details, circle No. 12 on Reader Information Card

No other tool saves so much time, material . . .

Arcair process cuts rework time 93%

10,000 J-47 jet engine nozzle cones of tough, heat-resistant stainless steel were disassembled for reworking by the Arcair process that cut time 93% over previous grinding methods. In addition, Arcair saved 89% on material costs.

This vital job was performed by the Carson Machine & Supply Company of Oklahoma City. The job was completed way ahead of schedule and because Arcair is a mechanical operation that does not depend on oxidation, it was not only effective in removing the stainless steel welds, but did not cause the slightest damage to these vital engine components.

You can save time and materials, too with Arcair. Call your local Arcair dealer or write for further information. Arcair Company, P.O. Box 406, Dept. 31, Lancaster, Ohio.

For details, circle No. 13 on Reader Information Card

For details, circle No. 14 on Reader Information Card→

World's biggest hopper trailer relies on M&T Murex electrodes

This 70-ton colossus can lug 95 cu. yds. of coal in one load. It is 47½ ft. long, 12 ft. wide, 13½ ft. high. When loaded, the trailer and its tractor weigh more than 119 tons. It takes rugged durable construction to withstand the continuous abuse this trailer takes as hundreds of tons of coal slam and pound it daily. In fabricating the world's largest hopper trailer, Marion Metal Products Co. relied exclusively on M&T Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, N.J.

M&T MUREX
PRODUCTS FOR BETTER WELDING

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

Illinois

TRANSMISSION LINES

Chicago—On September 8th, the Executive Committee of the *Chicago* Section held its first meeting at Armour Research Foundation, to launch the 1961–62 season. This year 19 meetings and special events have been scheduled. This is by far the most ambitious program offered by this section. The program was developed around the results of a program questionnaire sent to the membership last spring and the considered judgment of the sections directors to meet the diverse welding information needs of the greater Chicago Metropolitan Area. The evenings and locations for the meetings have been changed to include Tuesday, Thursday and Friday nights in the Loop, Calumet Area, Southwest Area and Northwest Area, so those persons who could not make the traditional third Friday of the Monday Loop meetings will be able to participate.

The Calumet Area dinner meeting held on September 14th was attended by 100 Chicago members and guests. Forest Daugherty of Edwards Valve Co. gave a brief description of the use of welding by the valve industry during the coffee period. R. W. Tuthill, the main speaker, then gave a very interesting and informative speech on "New Developments in Welding Field Transmission Lines." Application of this revolutionary welding technique was clearly illustrated with movies and slides.

TRAINING COURSE

Joliet—The *J.A.K.* Section held its first meeting of the year on September 14th at D'Amico's Restaurant. A short business meeting was held prior to the technical session. The Education Chairman, Bob Harris, outlined the first J.A.K. sponsored Welding Training Course to be held at Elgin High School, Elgin, Ill., starting November 15, 1961. The eight session course will cover both theory and shop fundamentals of arc and oxy-acetylene welding.

The speaker for the evening was Jack Kelly of the Harris Calorific Co., Cleveland, Ohio. Development of natural gas for use in burning and brazing along with technical advances in this field were covered by the speaker.

Michigan

EDUCATIONAL CHANGES

Detroit—On Friday, September 8th, the *Detroit* Section presented the "George N. Sieger Award" to Professor L. E. Wagner of the University of Michigan, at a dinner meeting of members and their guests.

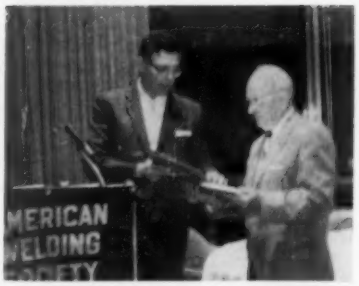
The "George N. Sieger Award" is an annual award bestowed on a member of the Detroit Section for best overall contribution and outstanding service to the field of welding and the SOCIETY.

Professor Wagner has tirelessly and unselfishly, for many years, served the SOCIETY and the industry. Among his many accomplishments were the promotion and directing of the building of the welding laboratory at the University of Michigan, having trained over 5000 men to weld, conducting a welding conference in Mexico City in 1955 at the request of our Government, and the publishing of many educational articles.

The Section was fortunate in having as speaker for the Award Dinner, Dr. William E. Stirton, a vice president of the University of Michigan and director of the Dearborn Center of the University. Dr. Stirton, in his presentation of "Many Moons Ago—Many Moons To Go" pictured the change in the educational system from 1900 to the present and from the present into the future. This change was caused by the industrial evolution; and the future will be governed by our leisure time which, of course, relates to the individual changes to be. Dr. Stirton likens one's life span to a circle which is ever growing larger due to a lowering of the mortality rate and longer life-span. He pictured our work-day portion of our life as a square set inside of our life circle.

The four sides of the square are the forces of (1) induction age into industry going up, (2) work day and work week shortening, (3) retirement age decreasing, and (4) increasing labor force and increased productivity per worker, pushing in

AN AWARD



Professor L. E. Wagner (right) receives the "George N. Sieger Award" from Past Chairman A. W. Brown at the September 8th Detroit Section meeting

AN ATTENTIVE AUDIENCE

One hundred members and guests at the September 14th Chicago—Calumet Area meeting listen to Mr. Tuthill speak on the automatic butt welding of pipe lines

SECTION MEETING CALENDAR

DECEMBER 1

PHILADEPHIA Section. Panel Discussion. "Metal Inert-Gas Welding; Arc Characteristics—Equipment—Production Problems."

DECEMBER 2

ST. LOUIS Section. Norwood Hills Country Club. Annual Ladies' Night. Dinner and Dance.

DECEMBER 4

SAN ANTONIO Section. "Welding Metallurgy," R. D. Wylie, Southwest Research Institute.

DECEMBER 5

PITTSBURGH Section. Porter Hall, Carnegie Institute of Technology. 7:30 P.M. Educational Course. Lecture 10—Titanium Alloys; Refractory Metals.

DECEMBER 6

SUSQUEHANNA VALLEY Section. Foothills Manor, Shickshinny, Pa. Dinner 6:30 P.M. "How to Save Money with CO_2 Welding," Roy Becker, International Harvester Co.

DECEMBER 7

LOS ANGELES Section. Rodger Young Auditorium. Annual Christmas Party.

NORTHERN NEW YORK Section. Hot Shoppes, Route 9, Albany, N. Y. "Power Supplies for Arc Welding," A. Lesnewich, Air Reduction Sales Co.

SAGINAW VALLEY Section. Saginaw, Mich. "Missile and Management," Leo Botz, A. C. Spark Plug Div. of General Motors.

DECEMBER 8

CHICAGO Section. Martinque Restaurant, Evergreen Park. 6:30 P.M. Seventh Annual Christmas Party.

DECEMBER 11

BOSTON Section. Quiz the Experts on Welding Processes. Moderator: Julius C. Ritter. "Resistance Welding," Frank Brandt; "Inert-Gas Shielded-Arc Welding," Iva Steen; "Metal-Arc Welding," Carl Hellmer; "Gas Welding and Cutting," Frank Lovejoy.

DECEMBER 12

DAYTON Section. President A. F. Chouinard and National Secretary F. L. Plummer.

HARTFORD Section. Villa Maria Restaurant. Panel discussion on Welding Problems. Panel—F. J. Wallace, C. Markland, H. McGlew and A. Reisch.

PITTSBURGH Section. Porter Hall, Carnegie Institute of Technology, 7:30 P.M. Educational Course. Lecture 11—Metallurgy of Allied Processes. Soldering. Brazing. Metallizing. Surfacing. Cutting.

TULSA Section. Ware's Cafeteria. Dinner 7:00. Meeting 8:00 P.M. "Health Aspects of Welding," L. E. Renes, Phillips Petroleum Co.

DECEMBER 13

CLEVELAND Section. Dinner meeting, Cocktails 6.00 P.M. Dinner 6:30. Hotel Manger. Panel Discussion: "New Developments in Welding Ferrous Metals."

TOLEDO Section. Toledo Yacht Club. Dinner 6:30. Meeting 7:45 P.M. Panel on Maintenance Welding.

DECEMBER 14

J.A.K. Section. North Aurora, Ill. Social.

KANSAS CITY Section. Cocktails, dinner, nontechnical program. "International Travel", Ted Brown, Sabena Belgian World Airlines.

NASHVILLE Section. Biltmore Restaurant. "Welding of Stainless Steels," Harry F. Reid, Jr., The McKay Company.

RICHMOND Section. "Stud Welding and Applications," John English and Tony Maladra, KSM Products, Inc.

DECEMBER 15

DETROIT Section. Stag Christmas Party. Company Night. American Legion Hall. 7:30 P.M.

INDIANA Section. Heritage Cafe, Indianapolis, "Aluminum and Practical Aspects of Tig and Mig Welding of Aluminum," Howard E. Atkins.

MILWAUKEE Section. Past Chairman's Night. After dinner speaker, National Secretary F. L. Plummer. "Progress Report on the Flux-Cored CO_2 Process," A. F. Chouinard, National Cylinder Gas.

PHILADELPHIA Section. Joint meeting with Naval Architects. "Assurance System Engineering."

DECEMBER 19

NEW JERSEY Section. Essex House, Newark. Dinner 6:30. Meeting 8:00 P.M.

PITTSBURGH Section. Porter Hall, Carnegie Institute of Technology. 7:30 P.M. Educational Course. Lecture 12—Review.

DECEMBER 21

STARK CENTRAL Section. Pollanaris Palm Garden, Alliance, Ohio. "Welding Behind the Iron Curtain," C. E. Jackson, Linde Co.

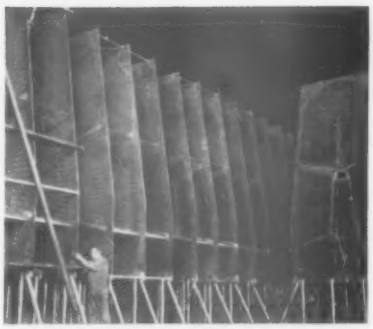
Editor's Note: Notices for February 1962 meetings must reach JOURNAL office prior to November 20th so that they may be published in the January Calendar. Give full information concerning time, place, topic and speaker for each meeting.

on the sides, ever decreasing the area of the square (the work portion of our lives).

HUNTING IN ALASKA

Saginaw—The *Saginaw Valley* Section met on September 14th for dinner and meeting at the High Life Inn, with an attendance of 62. Jack Honhart of the Atlas Welding Accessories, Inc., Ferndale, Mich., was the speaker.

Mr. Honhart showed movies that he had taken of ten hunting trips to Alaska. These hunts took place at various sites and on the Alaskan peninsula. The program was of a nontechnical nature, but the attendance was high. Although the program was somewhat longer than usual, Mr. Honhart held the attention of his audience throughout the film by presenting a running commentary and adding some personal anecdotes in conjunction with the film.



Largest

Tallest

Biggest

M&T Murex electrodes weld three huge ones

On the three preceding pages, you saw three more of the rugged applications in the long list of important, demanding welding jobs recently completed with M&T Murex electrodes.

That list includes a wide variety of products, requiring many different types of electrodes. With over 1000 types and sizes to choose from, the M&T Murex line includes just about every electrode you'll ever need.

The entire listing, including *Low Hydrogen, Iron Powder* and *Stainless Steel*, is in our new "Electrode Selector." Send for it.

M&T MUREX welding products

METAL & THERMIT CORPORATION

General Offices: Rahway, New Jersey

For details, circle No. 15 on Reader Information Card

New York

BRAZING

Bellmore—In the first meeting of the Fall season held on September 14th, the *Long Island* Section was fortunate in having D. C. Herrschaft of Handy & Harman speak on the subject "New Developments in High-Temperature Brazing."

Mr. Herrschaft's talk dealt with the latest developments in brazing alloys for elevated temperature service on honeycomb structures, space vehicles and jet engines. Included in his discussion were alloys containing gold and/or palladium in various amounts. The merits of these alloys will be explored in light of the present and future needs of industry.

HIGH STRENGTH STEELS

New York—The 1961–62 season got off to a rousing start for the *New York* Section on September 12th with a dinner meeting at Victor's Restaurant. John W. Flannery of the International Nickel Co. delivered his paper entitled "Welding of High Tensile Strength Low Alloy Steels." Identifying high strength steels as those containing less than 10% total alloy content, Mr. Flannery discussed the various welding processes normally associated with their fabrication. A variety of low alloy grades was covered, running through T-1, HY-80 and the new HY-150. The latter is a low carbon 5% nickel steel, further alloyed to develop 150,000 psi yield after tempering at 1050° F.

He augmented his presentation with a series of slides depicting a variety of mechanical and physical data at both high and low temperatures. Of particular interest were impact values for these high strength steels and the effects of carbon and nickel on particular physical properties. The importance of preheat was expressed in association with the determination of M_s by arithmetical calculation. Various points of information were brought out such as the slag removal problem presented when welding high nickel alloys with submerged arc.

The metallurgy of typical weldments was covered with the aid of slides indicating cross sectional studies. This led to a discourse on post weld treatments such as stress relief and recommended nondestructive tests. The importance of soaking time in relieving residual stresses was highlighted. A typical treatment might consist of holding 900° F for ten hours. Relative to inspection, careful examination of the root pass is mandatory in order to achieve satisfactory results. The notch sensitivity of alloys such as the manganese moly must be borne in mind. Additionally, low-hydrogen type coated electrodes must be thoroughly dry to insure proper deposit density. A 250° F rebake is usually recommended when in doubt.

A lively question-and-answer session following the talk indicated the interest aroused in the audience by this well-versed speaker.

WELDING ENGINEERING

Olean—The first 1961–62 meeting of the *Olean-Bradford* Section was held on September 19th at The Castle in Olean, N. Y. Following the dinner attended by 37 members and guests, John C. Kaluzny of the American Machine & Foundry Co., Buffalo, N. Y., gave a talk on "Welding Engineering" and its shop applications. An open discussion was held on shop welding problems and welding engineers responsibilities to the shop. Two good movies on the Titan Atlas Missile and the Sergeant Launcher were shown by Mr. Kaluzny.

RECOGNITION FOR A PAST CHAIRMAN

A. V. "Andy" Thoren is awarded honorary past chairman pin by H. D. Landis at the September 12th meeting of the New York Section. Looking on at left is past chairman M. D. "Dan" Bellware who also received a pin, and (right) current chairman, M. A. Feiner

North Carolina

EXHIBITION

Greensboro—Forty members and guests of the *Carolina* Section held a barbecue dinner on September 13th previous to meeting at the Section's booth at the Third Plant Engineering and Maintenance Show held in the new Memorial Auditorium.

After inspecting the display of

A NEW SEASON UNDER WAY

Some of the 40 Carolina Section members and guests who met on September 13th and inspected the Section's booth at the Third Plant Engineering and Maintenance Show at the Memorial Auditorium, Greensboro, N. C.

A TOUCH OF OLD AND OF THE NEW

Some of the many who enjoyed dinner and dancing at Annual Ladies Night held on May 20th by the Mahoning Valley Section

New Mahoning Valley Section officers for 1961–62 are extended best wishes by retiring Chairman R. Foxall (center). Left to right are: 2nd Vice Chairman T. Junk, Chairman J. Huna; Mr. Foxall; 1st Vice Chairman M. Oakley, and Secretary-Treasurer M. Bushwack

welded objects and Society literature in the booth, the members and guests gathered for a picture. Later they viewed and were well pleased with the large array of industrial exhibits there.

Oklahoma

INDUSTRIAL SAFETY

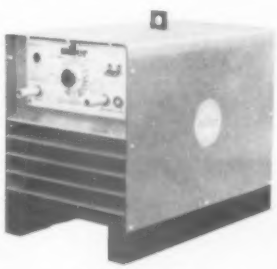
Oklahoma City—Howard N. Simms, zone representative for Jackson Products of Warren, Mich., was the speaker at the September 6th dinner meeting of the *Oklahoma City* Section held at Cattleman's Cafe.

In his discussion Mr. Simms covered the important subject of safety practices for the modern industrial worker with special emphasis on proper safety equipment. Included with the talk was a demonstration of the latest safety equipment: helmets, goggles, etc. manufactured by the Jackson Products Co. Mr. Simms stressed in his conversation that industrial personnel should be aware of everyday work hazards and be cognizant of the importance of wearing the proper safety equipment at all times.

PLANT TOUR

Tulsa—Following dinner at Bordens Cafeteria in Sheridan Village, 60 members of the *Tulsa* Section took part in a tour of the plant of the Dewey Portland Cement Co. It was a very interesting tour seeing

YOU GET MORE WITH A miller



GOLD STAR SRH

GOLD STAR SR

. . . Much more! More and better welds in less time, for one thing. You buy the welder just once . . . but every minute it's in use, it's bearing big interest in the form of increased production. More welder life too: Better basic design combines with Miller's own selenium rectifier to deliver performance, reliability and rectifier durability never approached elsewhere. And more economy too? Yes, especially more economy. That's why motor generator sets — even new ones — are being replaced daily with Miller Gold Star SR welders.

Write for descriptive literature on the Miller Gold Star SR or SRH, or see your local Miller dealer for a demonstration on the how and the why of the "More You Get With a Miller." He proves it! Also available upon request is a new and interesting pamphlet "Rectifiers for Welding" — which you should have.

miller ELECTRIC MANUFACTURING COMPANY • APPLETON, WISCONSIN

For details, circle No. 18 on Reader Information Card

NEW FACES AT A HEAD TABLE

A new season got under way for the York-Central Pennsylvania Section on September 19th when A. A. Holzbaur of the Sun Shipbuilding and Dry Dock Co. was guest speaker. Shown left to right at the head table are: R. R. Shanaberger, C. Dooley, Mr. Holzbaur, T. H. Boyer and W. E. Ciccarelli

the step-by-step process by which cement is made from the quarry to the finished product. The tour was under the supervision of Art P. Hunter, plant manager and Harold L. Eggen, assistant plant manager.

Pennsylvania

WORLD'S LARGEST DRY DOCK

York—The speaker at the September 19th dinner meeting and technical session of the *York-Central Pennsylvania* Section was Arthur A. Holzbaur, vice president in Charge of Operations for the Sun Shipbuilding and Dry Dock Co. Mr. Holzbaur showed slides of the construction of Sun Ship's new floating dry dock, the specifications of which are—lifting capacity, 38,000 tons; length, 740 ft; total width, 172 ft; usable beam, 140 ft, and depth from bottom of keel to top of wing wall, 66.8 ft.

Constructed in six sections two at a time on the standard ship ways. After launching each section, the sections were welded together to form one entire unit. Each of six sections contained four water-proof tanks for floating or sinking. First engineering and design was started in October 1960 and first ship was floated on four completed sections January 1961 or in less than four months.

Texas

CO_2 WELDING

Fort Worth—The *North Texas* Section met on September 14th at the Amon Carter International Airport for dinner and meeting. Guest speaker was Byron C. Motl of the A. O. Smith Corp., Milwaukee, Wis.

Mr. Motl is the author of a book now being published on the "How and Why of CO_2 Welding." He borrowed from this book for the first part of his program in discussing the different factors that it takes to make a good weld. In the latter part of the program he showed slides of his company's use of this process in the manufacture of automobile frames and miscellaneous parts.

Wisconsin

PLANT TOUR

Neenah—A plant tour was scheduled for the first meeting of the *Fox Valley* Section. Overly's Inc., provided a very interesting tour for 84 Section members. This plant does custom fabrication of stainless and mild steel. They are also specialists in the designing and manufacturing of high velocity dryers for the paper industry.

EMPLOYMENT OPPORTUNITY FOR ENGINEER

Here are the duties—

Working with AWS technical committees in gathering and correlating technical data; preparing minutes, reports and other records of committee activities; editing standards for publication as completed.

Disseminating technical information in answer to inquiries from industry.

Related duties as assigned.

Here are the qualifications—

Ability to work with technical men at all levels in a cooperative manner. This is necessary to deal successfully with committee personnel, AWS members and the general public.

A degree in engineering, any branch.

At least three years' experience in engineering work, preferably in welding or allied fields.

Here is an opportunity—

The man we are seeking has initiative and imagination and is interested in becoming familiar with welding in all its aspects and for every type of application. Salary will be commensurate with qualifications and experience.

AWS is seeking an engineer to join Headquarters' Technical Staff as Assistant to the Technical Secretary

If interested in being interviewed for this position, send a resume* of your education, experience and personal background to

Technical Secretary

American Welding Society

345 East 47th Street

New York 17, N. Y.

* **Will be held confidential.**

New Members

EFFECTIVE SEPTEMBER 1, 1961

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	203
Members	6,523
Associate Members	5,684
Students	361
Honorary Members	11
Life Members	31
Total	12,813

ARIZONA
Binkley, P. M. (B)
Diefenderfer, Clyde I. (B)

BIRMINGHAM
Bathurst, Lynn Leroy (B)
Olson, E. V. (C)
Poor, William R. (B)
Puryear, Ray (C)

BOSTON
Lynn, Harold A. (C)
Paley, Zvi (D)

CANADA
Mills, G. M. (C)

CAROLINA
Ingram, Hal B., Jr. (C)
Lee, Carl E., Jr. (C)

CHICAGO
Belknap, Carl H. (B)
Bushman, Don (C)
Clinard, Don (C)

CINCINNATI
Shafer, Edward R., Jr. (B)

CLEVELAND
Cullitan, Elmer J. (C)
Pierce, Hugh R. (C)
Smead, Harry F., Jr. (B)
Taliano, Charles (B)

DAYTON
Keil, L. E. (B)

DETROIT
Colosimo, James F. (C)
Hocking, Paul R. (B)
Kalvelage, Charles F. (B)
Keasal, Martin, Jr. (B)
Orth, Don (C)
Tibbetts, Arthur W. (B)

FOX VALLEY
Bauman, Melvin L. (C)
Ellestad, Eldred L. (B)
Riddle, Willis C. (C)

GREATER HUNTSVILLE
Nielsen, Paul (B)
Parr, Kenneth E. (C)

HAWAII
Bell, Stennett B. (C)
Carpenter, T. K. (C)
Ching, Lawrence A. (B)

HOUSTON
Voight, E. S. (B)

INDIANA
Boyer, Robert H. (C)
Galloway, Gale E. (D)
Holder, M. F. (C)
O'Brien, Robert W. (C)

IOWA
Holz, Wm. L. (D)

IOWA-ILLINOIS
Mc Mills, James C. (C)

KANSAS CITY
Stucky, V. E. (C)

LEHIGH VALLEY
Pensyl, Edwin H. (B)

LONG BEACH
Caffo, Thomas M. (C)
Moser, Delpha L. (B)

LONG ISLAND
De Vito, Joe (C)

LOS ANGELES
Mayes, George C. (D)
Mountfort, Ronald A. (B)

LOUISVILLE
Hartley, V. H. (C)

MARYLAND
Barnhart, William R. (B)
Biser, Marshall J. (C)
Coulter, W. V., Jr. (C)
Faust, William (B)
Gaebler, Fred E., II

MILWAUKEE
Gawin, Louis J. (C)
Weber, James L. (B)

NEBRASKA
Haile, James Stuart (C)

NEW JERSEY
Kossatz, Fred H. (B)

NEW YORK
Baker, Edward G. (C)
Barretts, Jack (C)
Fitzsimons, Robert (C)
Hoyt, W. B. (B)
Israelsson, Torsten I. (B)
Leone, Anthony (B)
Tietz, Edward E. (B)
Williamson, Leslie J. (B)

NIAGARA FRONTIER
Goodrich, Ralph M. (B)
Hunter, John S. (B)

NORTH TEXAS
Brouse, Jack H. (B)
Dunn, Edward J. (B)
Stewart, Dean A. (C)

NORTHEAST TENN.
Gritzner, Verne B. (B)

NORTHERN NEW YORK
Barnes, Philip A. (C)
Parker, Richard W. (B)
Stannard, Samuel C. (B)

NORTHWEST
Lorenz, Robert F. (C)

OKLAHOMA CITY
Jones, Wayne G. (C)

PEORIA
Platt, Arjay W. (C)

PHILADELPHIA
Boyes, Carol Joseph (C)
Galanti, Frank (B)
Hendrickson, Frank D., II (C)
Purcell, Ernest (C)
Raszka, William (C)

PITTSBURGH
Carney, Richard C. (B)
Edwards, Richard K. (C)
Evans, Stanley A. (C)
Fisher, William G. (C)
Gordon, Thomas, Jr. (B)
Lentz, Arthur H. (B)
Loerch, Robert C. (C)
Mainhart, Clyde (C)
Marchando, Thomas D. (C)
Skrobot, Joseph V. (C)
Teeple, R. J. (A)

PROVIDENCE
Schauseil, Robert I. (B)

PUGET SOUND
Eichhorn, E. G. (B)
Rosen, William M. (B)
Torpey, Lyle, F. (B)

SABINE
Finklea, James R. (B)
Kennedy, Hugh W. (B)

ST. LOUIS
Fank, Frank, J. (B)
Molitor, Julius, J. (C)

SALT LAKE CITY
Bills, Jesse A. (C)

SAN ANTONIO
Beversdorf, Eddie (B)

SAN DIEGO
Langford, Gerald J. (B)

SAN FRANCISCO
Brande, Harry J. (C)
Cain, John R. (C)
Chang, John W. (B)
Kraitzer, John (C)
Westby, Harold C. (B)
Winters, Robert C. (C)

SANGAMON VALLEY
Sleeth, Robert F. (C)

SANTA CLARA VALLEY
Dunbaugh, Walter A. (C)

SOUTH FLORIDA
Middleton, Robert G. (B)

SUSQUEHANNA VALLEY
Jopson, James E. (C)

SYRACUSE
Smith, David G. (C)

TOLEDO
Conrad, Robert (C)

TRI-CITIES
Gifford, Merle E. (C)

TULSA
Meadows, John Robert (C)

WASHINGTON, D. C.
Bumke, Richard W. (B)

WESTERN MICHIGAN
Aalderink, Gordon (C)
Thorpe, Ralph Wayne (C)

YORK-CENTRAL PA.
Brady, E. J. (A)

MEMBERS NOT IN SECTIONS
Ghosh, Ritindra (B)
Gruenberg, Jeheskel (C)
Honavar, Dinkar Shripad (B)
Lentin, H. J. (B)

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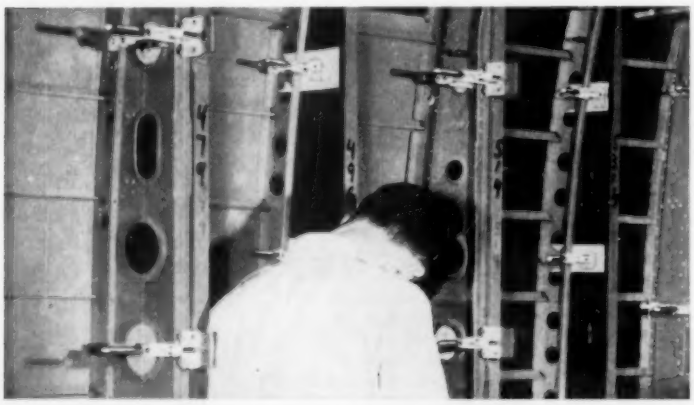

De-Sta-Co Toggle Action Clamps quickly and accurately position ribs of an aircraft fuselage while skin is applied.

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Singh, Mahendra Pratap (B)
Singh, Ramdayal (B)

Reclassification During September 1961

ANTHONY WAYNE

Kennedy, John P. (C To B)

BIRMINGHAM

Birkhead, H. C. (C To B)

BOSTON

Lawless, Richard J. (C To B)

CHICAGO

Provencher, Alfred (C To B)
Rudy, John F. (C To B)

CINCINNATI

Frame, Charles N. (C To B)

DETROIT

Wilson, Gerald M. (C To B)

HOUSTON

Quass, Louis M. (C To B)

J. A. K.

Perino, Charles D., Jr. (C To B)

LOS ANGELES

Godward, Charles L. (C To B)
Rogers, Robert (D To C)

MILWAUKEE

Laik, Theodore (C To B)

NEW JERSEY

Ebrahim, Kurt I. (C To B)
Lyons, Joseph B. (C To B)

NEW YORK

Wishnie, Frederick T. (C To B)

NORTH TEXAS

Stiles, Aubrey A. (C To B)

NORTHWEST

Murray, R. H. (C To B)

OKLAHOMA CITY

Garver, Jim (C To B)
Holmes, Carl A. (C To B)
Jewell, J. D. (C To B)

PHILADELPHIA

Burkitt, Samuel (C To B)

PITTSBURGH

Istone, William J. (C To B)

SAN ANTONIO

Jameson, Wayne A. (C To B)

SUPPORT YOUR SOCIETY

NEWS of the industry

Gas Plants for Chile

Airco Co., International, New York, N. Y., recently concluded an agreement to supply two oxygen plants and an acetylene generating facility to Industria Chilena de Soldaduras, S.A. (Indura), Santiago, Chile.

The plants—which will increase the use of industrial gases in the general metalworking industry and hospitals in Chile—are scheduled to go on-stream later this year.

Air separation column being loaded on freighter in New York City for shipment to Chile

Through previous business agreements between the two companies, Indura is under license to manufacture and distribute welding electrodes in Chile, using the trade name "Airco-Indura." Indura serves a major portion of the welding electrode market in Chile. The electrodes are manufactured primarily from locally produced raw materials.

Summer Welding Courses End

The Hobart Brothers Technical School, Troy, Ohio, recently completed its sixth summer of conducting refresher courses for Industrial Arts and Vo-Ag teachers in the art of teaching welding. Seventy-five instructors, from all parts of the country, attended the one-week long courses during June, July and August. Both arc and oxyacetylene welding techniques were demonstrated; followed by supervised practice on the part of the student teachers. The proper use of teaching text and teaching aids available from the school was explained. In commenting on the refresher courses, the consensus of those attending felt that they became much better qualified to teach welding and that interest in the welding programs at their schools will increase. Some teachers have attended for three or more years and are now offering specialized welding training to their students.

Summer courses end

Teachers interested in the courses should write to Howard Cary, Director of Hobart Brothers Technical School, Troy, Ohio.

Cargo Container Contract

A $209, 683 contract for construction of 467 controlled humidity Conex steel cargo containers was awarded to the Fab-Weld Corp., Simpson, Pa., Maj. Gen. William B. Bunker, commander of the Army Transportation Material Command in St. Louis, Mo., announced recently. It is the first contract for production of controlled humidity containers, and the third contract for Conex containers which Fab-Weld has received from the St. Louis command.

The controlled humidity containers will have double walls to insure against air leaks. A receptacle is provided for a desiccant. The boxes have been designed for shipment of small arms, such as the M-14 rifle. It is estimated that use of the new container will cut preservation and packing costs by approximately 50%.

COMING EVENTS

A Calendar of Welding Activity

AWS

April 9–13, 1962. 43rd Annual Meeting and Exposition, Cleveland, Ohio

ANS

Nov. 6–9. Atom Fair-61. Conrad Hilton Hotel, Chicago, Ill.

SFSA

Nov. 13–15. Technical and Operating Conference. Hotel Carter, Cleveland, Ohio.

ASME

Nov. 26–Dec. 1. Winter Annual Meeting. Statler Hilton Hotel, New York, N. Y.

NWSA

Nov. 27–28. Southeastern Zone Meeting. Dinkler-Plaza, Atlanta, Ga.

Nov. 30–Dec. 1. Southwestern Zone Meeting. Sheraton-Dallas, Dallas, Tex.

AIME

Dec. 6–8. 19th Annual Electric Furnace Conference. Penn-Sheraton Hotel, Pittsburgh, Pa.

600,000 pounds of ATOM·ARC® * helped create a welded waterfall at Niagara

The rushing waters of the Niagara River, diverted through this man made waterfall are energizing one of the world's largest hydroelectric power plants . . . The Niagara Power Project of the New York Power Authority. The project consists of two generating stations, the Niagara Generating Station and the Tuscarora Pump-Generating Station with a combined capacity of 2,190,000 kw.

Chicago Bridge & Iron Company constructed the project's 25 penstocks and also erected the 25 turbine scroll cases. This huge field construction job required in excess of 600,000 pounds of Atom·Arc iron powder low hydrogen electrodes.

Atom·Arc and the *Creative Craftsmanship* of CB&I is a combination that has worked together on many jobs such as this throughout the world, compiling an enviable record of success.

Here are some of the *job proven values* that have helped spell success for CB&I and other discerning fabricators: X-ray sound weld metal . . . excellent impact values . . . outstanding arc characteristics . . . plus a complete line, in strength levels from 70,000 psi to 120,000 psi and in analyses for welding nearly every type of low alloy high tensile steel.

To find out how these *job proven values* of Atom·Arc electrodes fit into your welding needs, send for our 64-page booklet, "Handbook for Welding Low Alloy High Tensile Steels." Write to Alloy Rods Company, Post Office Box 1828, York, Pennsylvania.

ALLOY RODS COMPANY

YORK, PENNSYLVANIA

SALES OFFICES AND WAREHOUSES • BOSTON • NEWARK • PHILADELPHIA • PITTSBURGH • BIRMINGHAM
CHICAGO • CLEVELAND • SAN FRANCISCO • EL SEGUNDO, CAL. • DISTRIBUTORS IN ALL OTHER PRINCIPAL CITIES

Thirteen penstocks, each 28 feet in diameter and 460 feet long, and at the far right, the scroll case installations which make up the Niagara Generating Station.

* **ATOM·ARC®** is the trade name for America's first and foremost iron powder low hydrogen electrode.

For details, circle No. 18 on Reader Information Card

OKI Sends Employees to Ohio State

E. C. Caluwaert, president of O.K.I. Supply Co., Cincinnati, Ohio, announced that two employees, Gerald Fry and Michael McManus, have been enrolled in the Ohio Wholesale Management Development Program.

This two year program of training men for managerial positions in wholesale organizations is fostered by the National Association of Wholesalers in cooperation with Ohio State University. The program is under the direction of William B. Logan, Professor of Education and Director of Distributive Education Institutes at Ohio State University.

During the 24 month period of this program, the men enrolled will alternately attend specialized classes at Ohio State University for two months "in school" session and then work in "on-the-job" sessions in the plants of sponsoring wholesalers.

Amperex Price Reduction

The Amperex Electronics Corp., Hicksville, L. I., N. Y., recently announced an across-the-board 50% price reduction on all Amperex PADT transistors. The increase went into effect on September 1.

Bay State Abrasive to Build in Luxembourg

The Bay State Abrasive Products Co., Westboro, Mass., has selected the Duchy of Luxembourg as the site of its third manufacturing subsidiary. The other two are located in Brantford, Ontario, Canada, and Torrance, Calif.

According to Arthur E. Gilman, president, excavation for the new subsidiary in the Commune of Steinsel, Luxembourg, will start in about two months. It is anticipated that actual grinding wheel production will commence within a nine months period. The basic lines will include vitrified, resinoid, reinforced resinoid and diamond abrasive products.

The countries to be served by Bay State Abrasives' new European plant include Belgium, Netherlands, Luxembourg, West Germany, Italy and France.

Hurricane Dam Pump Contract to Worthington

The U. S. Corps of Engineers recently announced that it has awarded a $1.5 million contract to Worthington Corp., Harrison, N. J., to supply Providence, R. I., with five giant pumps—the world's largest—for use in conjunction with the nation's first hurricane dam.

The pumps will be the vertical propeller type, each measuring more than 20 ft in diameter and approximately 31 ft from end to end. They will be installed side by side to comprise the largest pumping facilities in the world. Combined, they will be able to pump more than $4^1/_2$ billion gallons of water per day.

The Fox Point Dam, which is expected to be completed by 1964, will stretch 680 ft across the Providence River and will offer downtown Providence, which is below sea level, complete protection against raging storm waters caused by hurricanes.

Welding Repair Station Moves to Trucks

A new technique for service and maintenance of aluminum truck bodies in the field has been developed by Ravens-Metal Products, Inc., Parkersburg, W. Va. The new Ravens portable welding station can be dispatched from the company's Ellenboro, W. Va., plant immediately in any emergency.

Truckers are reported to like this new service since their rigs can be repaired during evening and night hours, without resulting in any loss of income due to truck downtime. While a few portable repair stations have been available for steel truck bodies, Ravens reports this is the first unit suitable for aluminum body repairs, since it requires more complex equipment and operator skill for in-field repairs.

Opens New Office

The opening of a new sales office in Salt Lake City, Utah, to extend the coverage of its existing Denver, Colo., office was recently announced by National Electric Welding Machines Co., Bay City, Mich.

Robert Callister of R. E. Duboc Associates, Denver, will represent the firm in Utah and Idaho, according to Harold Lange, National Electric sales manager.

New Helium Plant

The Air Reduction Pacific Co. has announced completion of a helium compressing plant at 4959 N. W. Forest St., Portland, Ore.

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Low Fuming Bronze
Nickel Silver
Silver Solder
Phosphor Copper
Phosphor Silver
Silicon Bronze
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Alloys meet AWS, ASTM & Govt. Specs.

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AUTHORS . . .

please note!

All authors interested in presenting papers at the AWS 1962 Fall Meeting to be held in Milwaukee, Wis., October 1–4 are advised that the usual forms, "An Invitation to Authors" and "Author's Application Form," were printed as a detachable insert in the October issue of the Welding Journal.

Additional copies of the forms may be obtained by writing to AWS Headquarters, 345 East 47th Street, New York 17, N. Y.

Helium for the plant, the second such facility to be built on the West Coast by Air Reduction, is secured from the government producing wells in Texas and Oklahoma. Special railroad cars transport the gas to Portland where it will be processed and then distributed in cylinders or cylinder trailers throughout the states of Oregon, Washington, Idaho and Montana.

Eutectic to Expand in San Francisco

Eutectic Welding Alloys Corp., Flushing, N. Y., recently announced that it was expanding its facilities in the San Francisco Bay area.

George R. McCloud

At the same time, George R. McCloud was appointed manager of the Service, Training, and Distribution Center for Eutectic in Oakland, Calif. Mr. McCloud was formerly with Trailmobile, Inc.

Chouinard Named to Patent Group

Alfred F. Chouinard, national president of the AMERICAN WELDING SOCIETY and director of research and development for the NCG Div., Chemetron Corp., Chicago, Ill., was recently appointed a member of the National Sponsoring Committee of the Celebration of the American Patent System by Chairman Dr. Vannevar Bush.

Completes 30 Years

On October 1st, the Machinery & Welder Corp., Skokie, Ill., completed its 30th year of business. A spokesman for the company stated, "We are thankful to our customers who have made the last thirty years so good to us and we hope to service them even better the next 30 years."

Dalweld Produces Aluminum Wire

The Dalweld Co., Inc., 11 Bertel Ave., Mt. Vernon, N. Y., recently announced its entrance as a processor of aluminum welding wire. Facilities include straightening and cutting machines, precision level layer winding machines, and triple degreasing tanks.

Symbols for Welding

Symbol of Quality

HI-AMP

Only Ground Clamps by HI-AMP have a tough spring that can't knock out. Broad contact base means a better ground and better welding results. Wide opening jaws fit any shape. Made of high copper alloy.

FREE Large 8½x11 chart shows symbols for arc, gas and resistance welding.

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Now you can check **WELD TIME** with new **PORTA-COUNT** cycle counter

only **$282**

Counts actual weld time during firing. PORTA-COUNT is light and small enough to carry easily—keep right on the job. Completely portable and self-contained with long life (up to 2 years) batteries. Counts single phases.

No Plug In **No Clips** **No Clamps**

PORTA-COUNT uses an inductive pick up to count, sensing magnetic field around power line, welding buss, transformer or electrodes.

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Minneapolis 4, Minnesota

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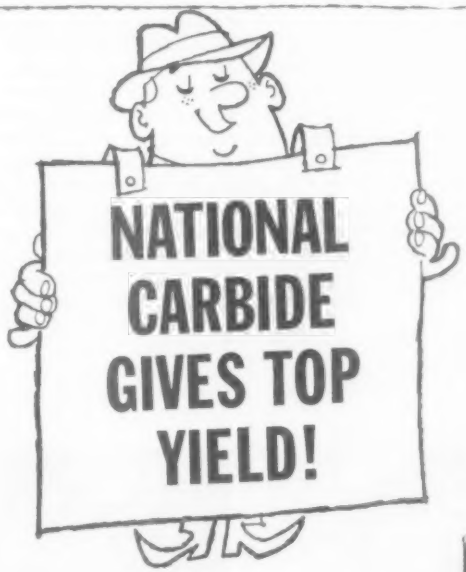

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PERSONNEL

Albom Named Chief Metallurgist

The Marquardt Corp. Van Nuys, Calif., recently announced the selection of M. J. Albom AWS, as chief metallurgist.

Mr. Albom was formerly associated with Aerojet-General Corp., and Reaction Motors, Inc., giving him extensive experience in both solid and liquid rocket motor systems.

MacLennan Named Assistant Manager

L. J. MacLennan Jr. AWS, former assistant manager of distributor sales in the Pittsburgh district, has been made assistant manager of distributor sales for the midwestern region of Air Reduction Sales Co., New York, N. Y. He will be responsible for planning, coordinating and directing distributor sales activities in the districts of Chicago, Detroit, Kansas City, Minneapolis and St. Louis.

Associated with the firm since 1934, Mr. MacLennan was appointed assistant manager of distributor sales for the Pittsburgh district in 1959, a position he held until his recent promotion.

Oros Joins Hobart

Alvin K. Oros AWS, a 1961 welding engineer graduate of Ohio State University, has joined Hobart Brothers Co., Troy, Ohio.

He served with the U. S. Navy and worked part time at Republic Steel Corp, and Weld-Rite Corp. He is also a member of the American Society for Testing Materials and the Society of Nondestructive Testing.

Miller Electric Names Two

Miller Electric Manufacturing Co. of Appleton, Wis., recently announced the appointment of W. D. Oldershaw AWS and E. R. Pierre to its Technical Sales Department.

Mr. Oldershaw, with 20 years experience in the welding field, was formerly with Electric Welding Development, Linde Co.

Ed Pierre was formerly with a missile manufacturing firm as research engineer.

M & T Announces Executive Changes

According to an announcement by Metal & Thermit Corp., New York, N. Y., H. E. Martin has become chairman and chief executive officer. Replacing him as president is Charles J. Beasley, formerly vice president and secretary of the Corp. H. W. Buchanan, vice president, has been named executive vice president.

Mr. Martin has been president of M & T since 1954. Prior to this time, he was with The Babcock & Wilcox Co. He is a Fellow of the American Society of Mechanical Engineers, a member of American Institute of Chemical Engineers, a director of Manufacturing Chemists' Association and a trustee of the United Engineering Trustees.

Mr. Beasley has been associated with Metal & Thermit Corp. since 1949, serving as assistant controller,

M. J. Albom

W. D. Oldershaw

E. R. Pierre

L. J. MacLennan, Jr.

A. K. Oros

C. J. Beasley

controller and vice president and secretary. He came to M & T from Lybrand, Ross Brothers and Montgomery, where he was senior auditor.

Mr. Buchanan joined M & T in 1947 as a chemical engineer. Since then, he has served as sales manager, and was appointed vice president and manager of the chemical division in 1960.

Chaney Joins Fibre-Metal

Jack Chaney has joined the sales staff of Fibre-Metal Southeast, Inc., of Decatur, Ga.

Recently completing intensive sales training, Mr. Chaney will cover southern Alabama, southern Georgia and Florida to provide sales training and field assistance to all distributors.

Erving Appointed to New Position

The appointment of Rowland Erving as director of market research has been announced by the McKay Co., Pittsburgh, Pa.

In the newly created position, Mr. Erving will be responsible for organizing the company's new market research department which will explore sales areas of the company's products.

WELDING ENGINEER for NUCLEAR SUBMARINES

An unusually attractive opportunity for a Welding Engineer now exists at the Portsmouth Naval Shipyard in the design, construction and repair of nuclear-powered HY80 hull submarines.

Experience and knowledge of advanced submarine hulls is desirable, but not required.

Excellent resort living on or near the ocean. Starting salary $12,210, plus all the benefits of Career Civil Service. Transportation will be paid.

Send personal information to: Director, Industrial Relations, Portsmouth Naval Shipyard, Portsmouth, New Hampshire.

DEVELOPMENT ENGINEER

Welding & Cutting Equipment

This growth company is engaged in the production distribution and application of industrial gases such as oxygen, nitrogen, argon, hydrogen and helium for the metallurgical and chemical industries. This challenging senior position heads up the engineering activities of our Welding Equipment Division. The qualified man must be an energetic self-starter with proven creative ability.

This position involves overall responsibility for the design and proto-type development of welding and cutting torches, regulators and flow meters.

Requires B.S. or M.S. in Mechanical Engineering with about 5 years experience in design and development of gas flow equipment, pressure regulators or high pressure equipment.

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• FINISHES FOR ELECTRONIC EQUIPMENT, COMPONENTS AND DEVICES. This engineer will develop processes and advise on applications of paints, lacquers, top coatings, metal cleaning methods. Chemist or ChE.

• RESISTANCE WELDING. This engineer will have his headquarters in fully-equipped welding laboratory, and undertake diverse advanced development projects in metals joining. His non-routine schedule will include vendor surveys, certification of processes, and qualification of equipment. Metallurgist, ME or EE.

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Falk Appointments

Harold F. Falk, president of The Falk Corp., has announced the appointment of Thomas F. Scannell as vice president-director of international operations. Formerly vice-president-general sales manager, he assumed these duties immediately and reports directly to Harold Falk. Don K. Lambert, who was manager of export sales, will be director of international sales.

Scannell's activities as general sales manager will be taken over by Sands G. Falk who has been appointed sales manager of the eastern division, and Kenneth O. Hood, who has been appointed sales manager of the western division. Both of these men will report directly to Walter Schneider, vice-president-director of sales.

The Falk Corp., manufacturer of mechanical power transmission equipment, operates its main plant in Milwaukee and wholly or partially owned plants in Sao Paulo, Brazil, and Mexico City, Mexico. In addition, they have numerous manufacturing license and sales agreements in other countries throughout the world.

Allis-Chalmers Appointments

Allis-Chalmers Mfg. Co., Milwaukee, Wis., recently announced the following appointments: H. C. Blair, manager of the Phoenix District; C. E. Temple, works purchasing agent at the Norwood, Ohio, works; R. R. Walker and R. Bell, respectively, as manager of the newly-formed Defense Material and Defense Systems Depts.; and A. J. Bennett as assistant to the general manager of the Allis-Chalmers Defense Products Div.

Temple succeeds R. N. Miller who will remain at the Norwood Works in an advisory capacity until his retirement.

McManus Named General Manager

Patrick L. McManus, former director of marketing services has been appointed general manager of Worthington Corp.'s Standard Pump Div., East Orange, N. J.

Mr. McManus joined Worthington in 1936 as a rock drill demonstrator and served as a general line salesman before service with the U. S. A. Corps of Engineers from 1942 to 1945.

He was named San Francisco district office manager in 1952, assistant general sales manager and Eastern Regional sales manager in 1959 and appointed director of marketing services in 1960.

OBITUARY

W. E. Adams

Walter E. Adams AWS of Guymon, Okla., died after a long illness on August 6, 1961. He was 63 years old.

At the time of his death, Mr. Adams, was chairman of the board of Adams Hard-Facing Co. of the same city.

As the first man ever to develop and process by hardfacing a farm tool for greater wearing life, Mr. Adams founded a new era for farm machinery. At the same time in 1927, he founded what is now the world-known company for hardfacing and heat treating processes done for original equipment manufactures. Walter Emerson Adams is survived by his wife, a daughter, three sons, eleven grandchildren and one great-grandchild.

Walter E. Adams

S. L. Ritter Appointed GWECO Vice-President

The appointment of Shelton L. Ritter as vice president and general manager of Gweco, Inc., was recently announced by Charles O. Stilwell AWS, president. Mr. Ritter started with Gulf Welding Equipment Co. right after World War II and served first as sales trainee, then salesman and then sales manager.

Mr. Stilwell also appointed Edward A. Mailhes as manager of the New Orleans store of Gweco, Inc., formerly Gulf Welding Equipment Co. Mr. Mailhes will be in charge of sales, store operation, apparatus repair department, electric repair department and truck routing.

Omark Appoints New Managers

The appointments of Donald Walker as market research manager and Don Berlinguette as advertising manager at Omark Industries, Inc., was announced recently by Edward P. Skralskis, executive vice-president of the Portland, Ore. firm.

Walker has been with Omark since 1956, and served as assistant personnel manager until his appointment as advertising manager in 1958. In his new position he will supervise marketing studies for both established Omark products and those under consideration.

For the past six years Berlinguette has been advertising manager for Omark Industries (1960), Ltd., Omark subsidiary in Guelph, Ontario, Canada. In his new assignment he will be responsible for advertising for the company's Oregon Saw Chain and Fastening Divisions within the U. S.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-758. Chief Welding Engineer. Engineering degree, age 38, single. Just completed one year's study as full-time student in Welding Engineering at Ohio State University. Ten years' production, design and R & D experience in alloy and exotic materials joining. Welding consultant for large fabricator (1000 operators). Instructor, lecturer, publications and technical committee member for ASME Code, shipbuilding, AEC, powerhouse and refinery welding. Nondestructive testing. Ferrous and nonferrous, all processes. Can organize and administer complete welding design and fabrication program. Résumé available.

A-759. Welding Engineer. Graduate engineer with several years experience in developing methods for both manual and automatic welding. Experience in training personnel, installing cost control methods and consulting during design stages for economical fabrication. Completely familiar with all welding processes used in heavy plate and pressure vessel manufacture. Several years' experience in fixture design. This young engineer desires management association with progressive company where production results can be achieved.

Current Welding LITERATURE

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

Electron Beam Welding

Electron Beam Welding Those Hard-To-Join Metals, M. Hablanian. *Assembly & Fastener Eng.*, vol. 4, no. 1 (Jan. 1961), pp. 36–40.

Gas Turbines

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CO_2-Shielded Overlayers, V. A. Shebanov. *Welding Production* (English translation of *Svarochnoe Proizvodstvo*), no. 4 (Apr. 1960), pp. 46–50.

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Space Heater Fabrication, J. A. Edwards. *Welding & Metal Fabrication*, vol. 29, no. 3 (Mar. 1961), pp. 82–8.

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Flame Cutting for Small Shop, C. F. Brown. *Am. Mach/Metalworking Mfg.*, vol. 105, no. 6 (Mar. 20, 1961), pp. 128–30.

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New Literature

T-1 Steel Welding Film

A new 16 mm. color-and-sound motion picture, "How to Weld 'T-1' Steel," is available from U. S. Steel Corp., for group showings.

Produced especially for training purposes, the 18-min motion picture will be particularly helpful to shop and field welding crews, welding trainees and vocational and engineering school students.

Step-by-step the new film shows how easy it is to insure sound welds in structures and equipment fabricated from this widely used engineering material.

Clear, concise narration goes right to the point with close-up photography of actual welding operations on "T-1" steel. The reasons why it is important to use the right electrodes, the right welding heat and the right procedure are explained and illustrated in orderly sequence.

For personal study or review of the techniques shown in the motion picture, a comprehensive booklet on "How to Weld 'T-1' Steel" will be presented to everyone who sees the film. Included with each booklet is a handy Welding Heat Input Calculator. The practical use of the calculator is demonstrated in both the film and the refresher booklet.

Arrangements for group showings of the new film can be easily and conveniently arranged by writing to: United States Steel Corp., Room 6363, 525 William Penn Pl., Pittsburgh 30, Pa.

Standard for Diamond Wheels

The Grinding Wheel Institute, 2130 Keith Bldg., Cleveland 15, Ohio, has announced the availability of a new American Standard entitled "American Standard Specifications for Shapes and Sizes of Diamond Grinding Wheels, Hand Hones and Mounted Wheels, B74.3-1961."

This document was approved as an American Standard on February 8, 1961. It contains thirty-seven pages of information on standard shapes and sizes of diamond grinding wheels. Each standard shape of diamond wheel is illustrated and accompanied by a table listing the major dimensions of each standard size in that shape category. A shape and size of a diamond grinding wheel has been included in this standard only after determining on the basis of sound engineering practice, whether or not it was designed, dimensionally, to perform the job for which it was intended.

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Three-Phase Rectifier, DC Arc Welder

New bulletin (No. 4609.1) describes performance features and construction details of a new line of welding machines being manufactured by The Lincoln Electric Co. Cleveland 17, Ohio. Designed to perform equally well in the shop on maintenance or production applications or outdoors on a construction site, the Idealarc R3M 3 phase rectifier D-C arc welder will handle any type of manual arc welding electrode. In addition the high capacity model can be equipped for semi-automatic submerged-arc welding.

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Efficiency Suggestions Compiled

An easy-to-use lighting calculator designed for shipyard use, a portable electric oven for baking paint, and a mobile welding unit are described in a collection of machine shop practices recently adopted by the Navy's Bureau of Ships for use by its industrial facilities. Compiled from suggestions made by Navy employees, the collection of 72 time- and labor-saving devices has been released in an illustrated booklet through the Office of Technical Services, Business and Defense Services Administration, U. S. Department of Commerce, Washington 25, D. C.

High Vacuum Equipment Catalog

A new 23 page catalog describes high vacuum systems, instruments and valves is available from F. J. Cooke, Inc., 145 Water St., South Norwalk, Conn.

Featured under systems are high temperature, cold jacket furnaces and special purpose vacuum evaporators. The instrument section includes an ionization gage control with automatic range switching. A series of ring angle cast stainless steel valves is described. Detailed descriptions and technical specifications are provided.

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ASTM Methods for Analysis of Metals

The 1961 Book of ASTM Methods for Chemical Analysis of Metals is said to be the latest volume in the series published by the American Society for Testing Materials, providing an authoritative source of reliable and accurate methods of analysis, and supplemented by many new testing procedures perfected and approved by Committee E-3 on Chemical Analysis of Metals.

The volume reportedly contains various methods included in previous editions which have been brought up to date, newer methods that take advantage of shorter or more precise procedures which have been developed, and methods for additional metals.

This book is an integral part of the Book of ASTM Standards, although not assigned a part number, and is the only publication in which ASTM chemical analysis of metals methods are found in convenient form.

Copies of this book may be obtained from ASTM headquarters, 1916 Race St., Philadelphia 3, Pa., at $11 each. To ASTM members, $8.80.

Type H Leak Detectors

Bulletin GEA-6817A, eight pages, describes Type H line of portable, halogen sensitive, electronic leak detectors for industry, research and defense applications is available from the General Electric Co., Schnectady 5, N. Y. All leak detectors discussed are sensitive enough to precisely locate pressure and vacuum leaks as small as $^{1}/_{100}$ cu in./day. They include: Gun Detector, Type H-2, and Pencil Probe Detector, Type H-5, for inspection of welds, seams, joints and other suspected areas of leakage in pressure systems; Stationary Detector, Type H-3, for completely automatic production line leak testing; Vacuum Detector, Type H-4, for vacuum system leak checks. Other related General Electric leak detectors described are: General Service Leak Detector, Type H-6, for air conditioning and refrigeration field service, and, helium-sensitive Mass Spectrometer Leak Detector, Type M-60, for ultra-sensitive applications in electronics, nuclear, air craft and missile industries.

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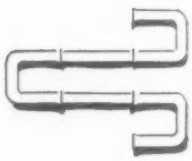

Automobile air conditioning units called for a low-cost but highly corrosion resistant heat exchanger with freon-tight seals in aluminum tubing. ALL-STATE developed a cadmium-zinc alloy that was low in cost, resistant to all atmospheric conditions, and leak-proof. Same alloy now used for repair of automobile radiators.

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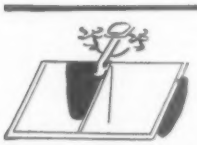

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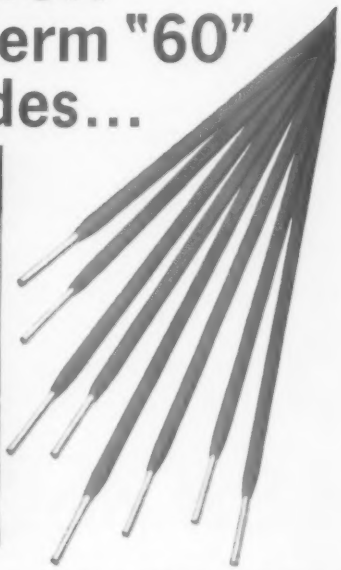

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Technical Library on Electric Welding

One of industry's most complete libraries of technical papers on electric welding is being offered by Linde Co., Division of Union Carbide Corp., 270 Park Ave., New York 17, N. Y., which has developed many of the manual, semi- and fully-automatic arc welding processes used today.

The "Linde Electric Welding Library" contains process and application details on short arc welding, mig and tig welding and spot welding, submerged-arc welding, CO_2-flux arc welding, and plasma arc cutting, welding and weld surfacing. These papers have been presented at meetings of technical societies and been published in industrial journals. New papers on similar topics will be added to the Library as they become available.

These technical papers, an excellent source of basic information on arc welding developments, are ideal for welding, production, design and metallurgical engineers, purchasing directors and general management in the metalworking industry.

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Safety Catalog

A new illustrated 20-page catalog (N-177) called "Personal Protective Equipment for Welding and Cutting" is available from the NCG Div., Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill.

There are 68 photographs and drawings featuring helmets, hand shields, goggles, safety glasses, safety hats and caps, face shields, portable screens, gloves and mittens and accessories.

The $8^1/_2$ x 11 in. catalog includes head, eye and face safety equipment manufactured by the Safety Products Div., American Optical Co., for which NCG recently became national distributor.

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Shielding Gas Selection

Reprints of an article by I. D. Holster entitled "How to Choose the Right Shielding Gas" (Ard-135) are now available from Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. The article appeared in the Dec. 12, 1960, issue of *Steel magazine*.

Liberally illustrated with charts and photographs, the article presents a handy basic guide for the selection of the most efficient shielding gas for welding any metal with either the tungsten- or metal-arc processes. The gases—argon, helium, carbon dioxide and combinations of argon-helium, argon-oxygen, argon-hydrogen and nitrogen-hydrogen—are discussed in detail. Applications and advantages of each process are given.

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Hard Surfacing

A 64-page catalog of individual data sheets on their complete line of hard surfacing is available from Alloy Rods Co., P. O. Box 1828, York, Pa. The catalog includes Wear-Arc and Wear-Flame hard surfacing electrodes and rods for manual applications, Wear-O-Matic hard surfacing wires and wire feed units for semiautomatic and automatic applications.

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Air Torch Catalog

Atmospheric air torches for use with both acetylene and propane, along with regulators and a complete line of tips and accessories for heating, soldering and light brazing, are described in a new, fully illustrated catalog by Acetylene Supply Co., Woodbridge, N. J.

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Spooled Copper Wire

All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y., announces a new bulletin describing its Spollarc® copper and copper-based welding wires for the inert-gas welding processes. The bulletin gives government specifications, AWS, ASTM, ASME, Boiler and Pressure Vessel Codes on four spooled alloys; Deoxidized Copper, Silicon Bronze, Aluminum Bronze and Phosphor Bronze ("C").

Procedures covering tungsten- and metal-arc welding methods are given, together with wire diameters, weight per foot of filler metal and spool sizes.

Data sheets for each of the copper alloys include typical applications with additional information on joining dissimilar metals. A cross-indexed selection chart provides handy reference for joining cast, wrought or forged coppers, steels, stainless steels and specialty bronzes.

Typical wire compositions and mechanical properties for the 4-spooled copper alloys are shown in composite charts with the tensile strength, elongation and hardness ratings for each alloy.

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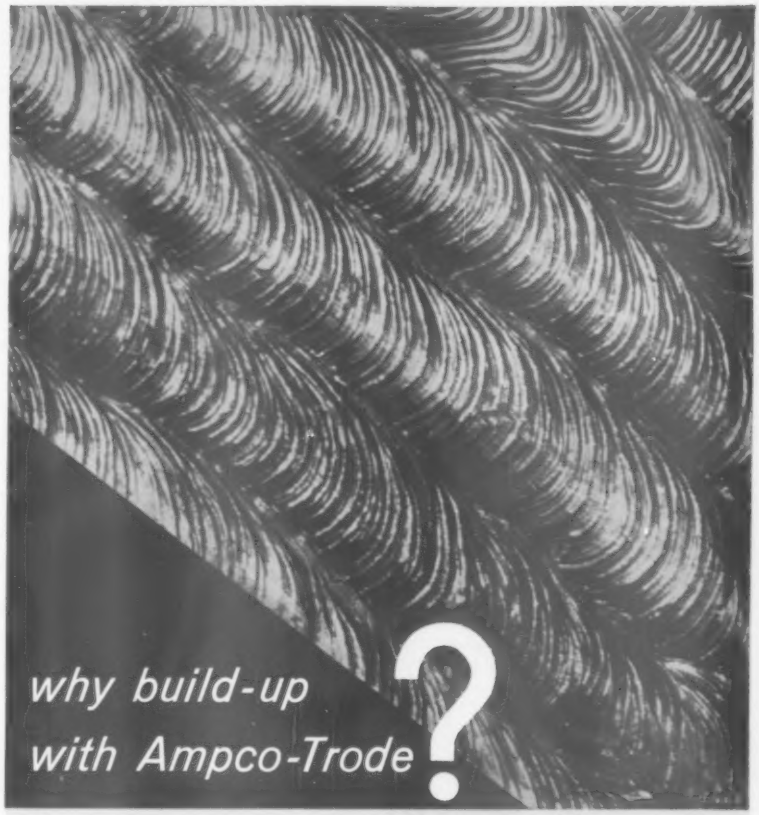
Welding Wires, Rods Catalog

A comprehensive catalog (F-1486) of Oxweld electric welding wires and rods is available from Linde Co., Division of Union Carbide Corporation. It describes the various wires for all continuously-fed electrode welding processes, such as submerged arc, mig and CO_2-flux, and wires and rods used as filler metals for tig welding. The guide lists available forms, sizes, packages and chemical compositions.

New catalog details the recommended welding processes and Oxweld wires and rods to meet various AISI, AMS, ASME, AWS (ASTM), Federal and U. S. Department of Defense (including MIL) specifications for electric welding of aluminum, copper, aluminum-, phosphor-



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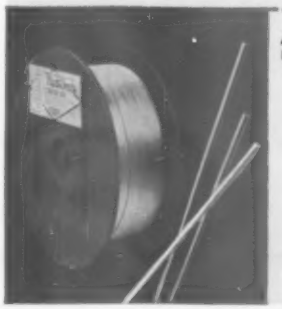

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and silicon-bronze, carbon steel, stainless and alloy steels. A special table covers process and application data, including physical properties of the weld metal, for the ten most-frequently-used carbon wires and the steels to which they are applied.

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REVIEWS OF NEW BOOKS

(Foreign book reviews are by G. E. Claussen, contributor to the World Wide Welding News column.)

Resistance Welding (Widerstandsschweissen) vol. 21 of the books published by the West German Welding Society; Deutscher Verlag Fur Schweisstechnik, 1961, 104 pages.

The nine papers delivered at the Fourth Stuttgart Conference on Resistance Welding in October 1960 are reproduced in this volume. Paper No. 1 shows that automation by resistance welding must require minimum capital expenditure for maximum labor swing in order to be most efficient economically. For the first half of 1960, the value of resistance welding machines made in Germany was 20 million marks (5 million dollars), which was 35% of the total value of electric welding machines produced. Paper No. 2 describes multiple-electrode resistance welders with automatic feed parts. Paper No. 3 illustrates controls embodying transistors. Papers 4 and 5 illustrate transistor applications to digital half-cycle counters particularly in the automotive industry.

Papers 6 and 7 deal with high-capacity flash welders. Graphs show the kwhr and time required for various cross sections. The flash welding of railroad and crane rail joints, including switch joints is described. The creep strength of flash welded Nimonic 75 at 1200° F was found to be 17,000 psi for 40 hr compared with 19,500 for base metal.

Paper No. 8 is the longest and describes resistance and induction welding of the longitudinal seams of steel piping and tubing. Roll seam welding requires square edges and removal of scale in the way of the rolls. High frequency welding with sliding tungsten-silver alloy contacts at 450,000 cycles is particularly suitable for thin-wall tube because the heated zone is narrow. Nonferrous metals, even copper, can be handled. Induction welding at 4000 cycles without sliding contacts does not require descaling or squaring at the edges. Wall thicknesses from 0.10 to ½ in. can be welded with flat coils. The ninth paper reviews the principles and applications of condenser discharge welding referring briefly to the co-axial process whereby the two electrodes are on the same side of the sheet.

Welding Handbook for Designers (in German) by Alexis Neumann, vol. 1, Fundamentals, 584 pages, 525 figures; second edition, completely rewritten, 1961, published by Fried. Vieweg & Sohn, Branschweig, East Germany. German title is "*Schweisstechnisches Handbuch Fur Konstruktsure.*" Price is about $6.00.

The author of this book is a member of the staff of Central Welding Institute of East Germany and has earned an international reputation for his research on the fatigue strength of welds. The book is the first of four volumes. The other three will be published within a year and will cover steel structures, machinery and boiler design, and vehicular design.

Volume 1 is divided into two sections and an appendix. The first section discusses static and fatigue strength (75 pages), distortion and shrinkage stresses, and welding sequence (61 pages), selection of base and filler metal (97 pages), heat treatment (15 pages), welding symbols (28 pages), and principles of design for fatigue (37 pages). Section 2 deals with the design of lightweight and tubular structures (60 pages). The appendix (131 pages) lists the properties of structural sections.

It is not an elementary textbook, and emphasizes the importance of poly-axial stresses and minute notches in the performance of welded structures. The treatment is not mathematical, but relies to a great extent on discussion of experimental results. References quoted in the book are almost exclusively German. Students in Germany are fortunate to have available a book that so thoroughly describes the materials and welding practices of their country.

New Products

Gas Welding and Cutting Outfits

Two new oxy-acetylene welding and cutting outfits have been introduced by Linde Co., Division of Union Carbide Corp., 270 Park Ave., New York 17, N. Y. The new units, called the Purox "One Hundred" and "One Thirty," both include apparatus which is unconditionally guaranteed for one year against defects in materials and workmanship. They are being marketed at special low prices.

Featured in the "One Hundred" outfit are the lightweight welding torch and the compact cutting attachment. Three welding heads for welding metal up to $^3/_8$ in. thick and a cutting nozzle for slicing 2-in. steel, are also supplied. Small, precision, field proved oxygen and acetylene regulators add to the portability of the new, low-cost outfit. The medium-range welding torch and three welding heads for welding up to $^3/_8$ in., (capacity, up to 1 in.) and a rugged cutting attachment with a nozzle for cutting up to 4 in., (capacity, up to 8 in.) are the center of attraction in the "One Thirty" oufit.

For details, circle No. 101 on Reader Information Card.

Micro-Ground Flux Brazing Rods

A new micro-ground flux having noncharring and chip resistant properties has been extruded on three standard brazing alloys by All-

State Welding Alloys Co., Inc., 249 Ferris Ave., White Plains, N. Y.

All-State Nos. 11, 13 and 41—for nickel silver brazing, nickel silver build-up and general purpose brazing—will continue to be the same high quality alloy core wire with an improved flux coating.

A new plastic-based binder gives the flux unlimited shelf life.

For details, circle No. 102 on Reader Information Card.

Heavy Duty 500 Amp Torch

Tec Torch Co., Inc., 15 Clark Court, East Rutherford, N. J., has added another gas tungsten-arc welding torch to its ever increasing line: the 500 Amp No. 421.

Engineered to provide a continuous welding work range of from 1 to 500 amp, the torch embodies these principal exclusive features: one-piece construction eliminating costly parts replacements; tip-of-torch cooling which does away with cooling off time entirely; and, easy adaptability to all standard Tec Torch nozzles and chucks.

For details, circle No. 103 on Reader Information Card.

Extruded Coated Electrode

A new aluminum electrode with an extruded coating (AWS Grade AL-43) for all-position welding, with direct current reverse polarity, of aluminum plate, sheet and casting has been made available by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y.

The Airco 43 electrode operates smoothly with an easy-to-control, quiet arc, while providing a dense, low spatter deposit. This extruded aluminum electrode features low amperage application and easy slag removal. It provides tensile strength yields up to 28,000 psi.

Airco 43 is usable in flat, horizontal and vertical arc welding positions and has outstanding qualities in repairing cracks, build-up of worn parts, cladding and reinforcing. It is ideal for welding tanks, railings, pipes and is also used in truck and automotive construction and repair.

Airco 43 comes in two sizes, $^1/_8$ in. diam by 14 in. in length and $^5/_{32}$ in. diam by 16 in. in length. It is shipped in five pound packages.

For details, circle No. 104 on Reader Information Card.

High Temperature Paint

Recent progress in the development of exotic resins and refractory materials has made possible even further improvement in the performance characteristics of this custom-made coating by Tempil° Corp., 132 W. 22 St., New York 11, N. Y.

Some salient properties of Pyromark° are: ease of application—

can be applied like any ordinary paint by brushing or spraying; refractory nature—after a brief preliminary cure at 400° – 600° F, it will survive temperatures of 2500° F and, in some cases, higher.

For details, circle No. 105 on Reader Information Card.

Stepless Filler-Wire Feeders

Two new filler-wire feeder units for automatically feeding cold filler wire in gas tungsten-arc (Heliweld and gas metal-arc (Aircomatic) welding are now available from Air Reduction Sales Co., 150 E. 42 St., New York 17, N. Y. The feeders can be used for both automatic and semi-automatic applications.

Both model feeders are identical except for wire-feed speed ranges. One has a range of 12 to 84 ipm, the other feeds from 20 to 140 ipm.

For details, circle No. 109 on Reader Information Card.

LINDE ELECTRIC WELDING

PLASMARC

New...very-thin, fused deposits with controlled dilution
New...high-speed, dross-free cuts in 5-in. thick metals

LINDE, inventor of plasma arc processes, announces *new* PLASMARC weld surfacing and *advanced* PLASMARC cutting. What is plasma arc? It is a flow of gas forced through an electric arc, constricted in a small-bore torch nozzle, and accelerated to form an intense jet. It combines electrical heat with the latent heat of highly-excited ionized gas atoms to reach one of the highest known metal-working temperatures (30,000° F.). It will melt any known metal.

A TRUE WELD

PLASMARC *weld surfacing* is true welding—not coating or plating—achieved by feeding powdered metal through the plasma arc into a weld puddle which freezes to form the deposit. Its precision eliminates excess buildup—ideal for such parts as valves, plowshares, seals . . .

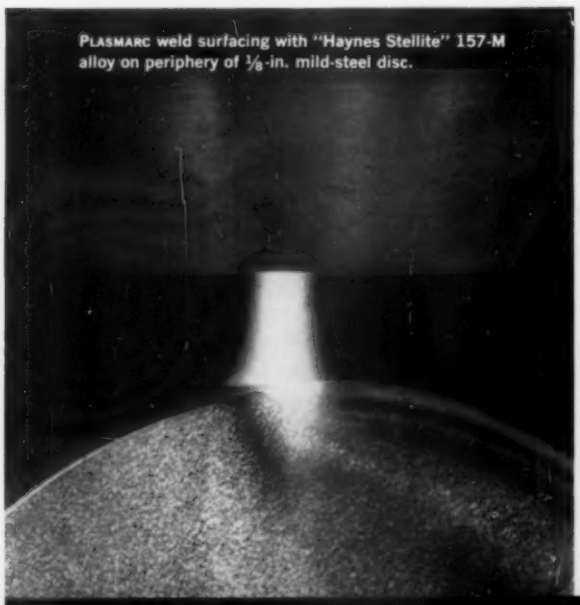
PLASMARC weld surfacing gives precise control of penetration of overlay metal into base metal—as little as .005 in. or higher. Gives precise control of dilution with base metal—from 5% up to 50%. Provides one-pass deposits as thin as .010 in., as thick as 3/16 in., with a wide range of metals and alloys. Produces widths from ⅛ in. to 1 in. or more, speeds over 20 ipm at 95% deposition efficiency, flatter and smoother deposits than other fusion processes.

4000 FT./SEC. VELOCITY

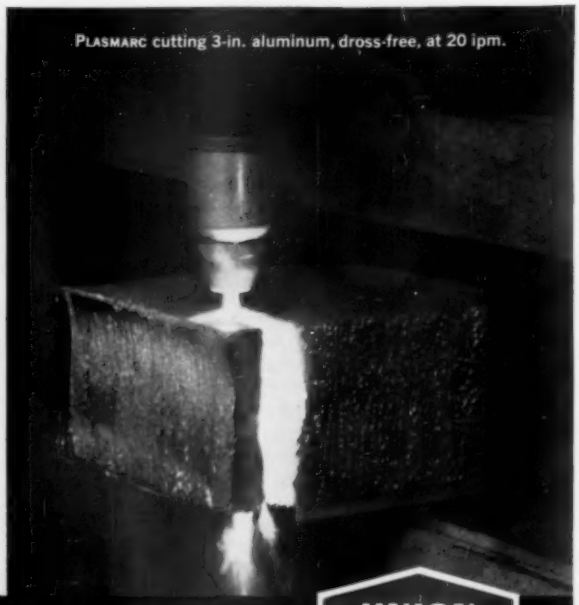
PLASMARC *cutting* uses a near-sonic velocity plasma jet (4000 ft./sec.). It easily melts-and-forces a narrow kerf through both ferrous and non-ferrous metals with little or no change in metallurgical properties. After six years' success, it is replacing shearing, sawing and powder cutting—slower methods which often require machining of the cut edge.

PLASMARC cutting has been further developed—heavy-duty equipment, higher current capacity—to handle increased metal thicknesses. It cuts aluminum, magnesium and copper up to 5-in. thick and stainless steel up to 2 in. thick, dross-free. It clean-cuts 4-in. thick stainless, nickel, carbon steel (requires no iron powder), "Monel," "Inconel," cast iron, high-alloy and clad steels. It makes precise, high-speed cuts up to 300 ipm, holds tolerances to 1/16 in., leaves a heat band as thin as .006-in. wide.

Get full details . . . see a "live" PLASMARC demonstration. Contact your local LINDE office or write direct.



PLASMARC weld surfacing with "Haynes Stellite" 157-M alloy on periphery of ⅛-in. mild-steel disc.



PLASMARC cutting 3-in. aluminum, dross-free, at 20 ipm.

LINDE COMPANY
Division of Union Carbide Corporation
270 Park Avenue, New York 17, N. Y.

UNION CARBIDE

For details, circle No. 35 on Reader Information Card

Polishing and Grinding Machine

After 2½ years of development, Geoscience Instruments Corp., 142 Maiden Lane, New York 38, N. Y., has introduced a polisher-grinder which is now available to metallurgical and quality control laboratories for fine metallographic specimen preparation.

The polisher is a versatile quality machine which incorporates an 80–

1200 rpm variable speed control with a powerful semiconductor safety circuit ½ hp dc motor providing a constant torque at all loads. Vibration and rollout are virtually eliminated. Compact low silhouette reduces operator fatigue. The pan, lap, polishing wheel and cover can be changed as one unit in seconds without danger of contamination.

For details, circle No. 111 on Reader Information Card.

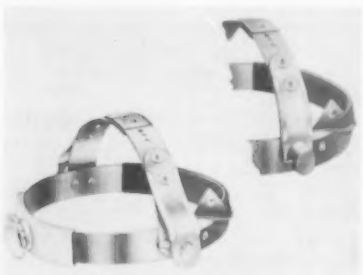
Headgear for Welding Helmets

A new, free-floating welding helmet headgear of plastic fabrication is now being produced by Fibre-Metal Products Co., 5th & Tilghman Sts., Chester, Pa.

Designated "3-C Headgear," this new unit is reportedly not affected by moisture, is flexible for comfortable conformity to any head, is adjustable for perfect fit around and on the crown of the user's head.

The free-floating design avoids direct head contact with the helmet shell. There are no side pressures or front-to-back pressures imposed by the welding helmet.

All metal parts are aluminum for



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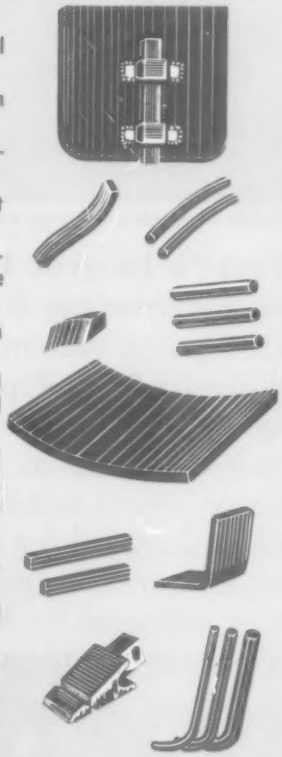
BUCKET SIDES — cut from Manganal Flat Bars.
BUCKET CUTTING EDGE FOR WORN LIP — bend from Manganal Hot Rolled Wedge Bar.
BUCKET TOOTH SOCKETS—reinforce with Manganal Round Bars.
BUCKET CUTTING EDGES BETWEEN TEETH — cut from Manganal Hot Rolled Wedge Bars.
BUCKET FLOOR LINER — flame cut and bend from Manganal Hot Rolled Plate.
BUCKET HITCH PINS & HINGE PINS — cut from Manganal Round Bars.
CRACKED BUCKET LIP—repair with Manganal Electrodes for extra strength.
BUCKET HEEL — reinforce with Manganal Flat Bars.
BUCKET TAPERED LIP—form from various thicknesses of Manganal Round Bars.
BUCKET TEETH — repoint with Manganal Wedge Bars.



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WELD WITH ARCOS STAINLESS ELECTRODES

Job report courtesy of Southwest Welding & Mfg. Div., Yuba Consolidated Industries, Inc. Alhambra, California

World's largest liquid oxygen tank calls for pioneering in stainless welding. This 75,000 gallon vacuum bottle for liquid oxygen was fabricated from Type 321 stainless. Specifications required strong sound welds having maximum notch toughness at low temperatures. After extensive impact testing at minus 320°F Arcos electrodes, designed for low carbon and specific ferrite ranges, were selected. The precise weld metal properties delivered by Arcos on this job are available for all your stainless welding jobs.

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corrosion resistance, light weight and better durability. The new ratchet adjustment is designed for a gloved hand.

For details, circle No. 112 on Reader Information Card.

Spike Power Bench Welders

The first line of standard Spike Power bench welders designed and built specifically for precision welding of transistors and minute electronic components is announced by National Electric Welding Machines Co., 1846 Trumbull St., Bay City, Mich.

Known as National's "S" series, the line is composed of four models

varying in work capability and designated as size O; S-1; S-2; and S-3. All but size O are also available with standard welding controls.

The models also vary in transformer and firing tube capacity and in weld pressure delivered from a low of two pounds for size O to a maximum 500 pounds on the S-3 model.

For details, circle No. 113 on Reader Information Card.

Heavy-Duty DC Capacitors

Corson Electric Mfg. Corp., 540 39th St., Union City, N. J., are producers of a new Type RA capacitor designed for use in power supplies, voltage doubling circuits, communication receivers and transmitters, X-ray equipment, energy storage, and other electronic applications.

Designed for 10,000 hr operation without derating at 85° C, they are also suitable for use from −55 to +115° C. Heavy 18 gage steel containers are gas tungsten-arc welded for maximum protection against shock and vibration. Prime and finish coatings reportedly resist

high humidity and salt conditions. Terminals are wet-process glazed procelain bushings, spaced to eliminate flashover. Multiple layers of tension-wound, super-calendered, high-density kraft capacitor paper are used between foils to insure long, trouble-free life according to the manufacturer. To withstand high voltage stress with safety, capacitors are impregnated with chemically pure, high viscosity polybutene oil. Reliability is further insured by the long drying and baking cycles at high temperature and vacuum in addition to the long impregnation cycles. Ten different voltage ranges are available from 10 to 60 kv dc.

For details, circle No. 114 on Reader Information Card.

Air-Cooled Manual Holder

A 160 amp air-cooled manual tungsten inert-gas (Heliweld) holder, featuring a thumb operated gas valve for increased speed and economy, has just been made available by Air Reduction Sales Co., 150 E. 42 St., New York 17, N. Y. This is the only 160 amp ac or dc continuous capacity air-cooled holder on the market with a built-in gas valve for savings in both time and gas consumption.

The holder is easy to handle since

its $2^{7}/_{8}$ in. head clearance permits its use in more confined spaces.

A variety of nozzle orifice sizes are available in $1^{1}/_{4}$ and $1^{5}/_{8}$ in. lengths. An added feature is the interchangeability of such accessories as collet cap assemblies, collets and nozzles with those in the water cooled holder rated at 350 amp dc.

The new holder also features minimum stub loss, efficient gas shielding and elimination of high frequency leakage. Tungsten electrodes from 0.20 through $^{5}/_{32}$ in. diam and from 2 to 7 in. in length can be accommodated. Argon, helium or mixtures of argon and helium shielding gases can be used.

For details, circle No. 115 on Reader Information Card.

BETTER WELDING WITH ARCOS SERVICE

Know what you're getting—know what you're going to get. The combination of Arcos quality filler metals and Arcos technical assistance brings you *predictable* welding results you can depend on time after time—job after job. The skills of the Arcos research and service team are available to help solve your problems—to give you top performance on every welding job. You can add quality to your welding and save money by consulting your Arcos representative.

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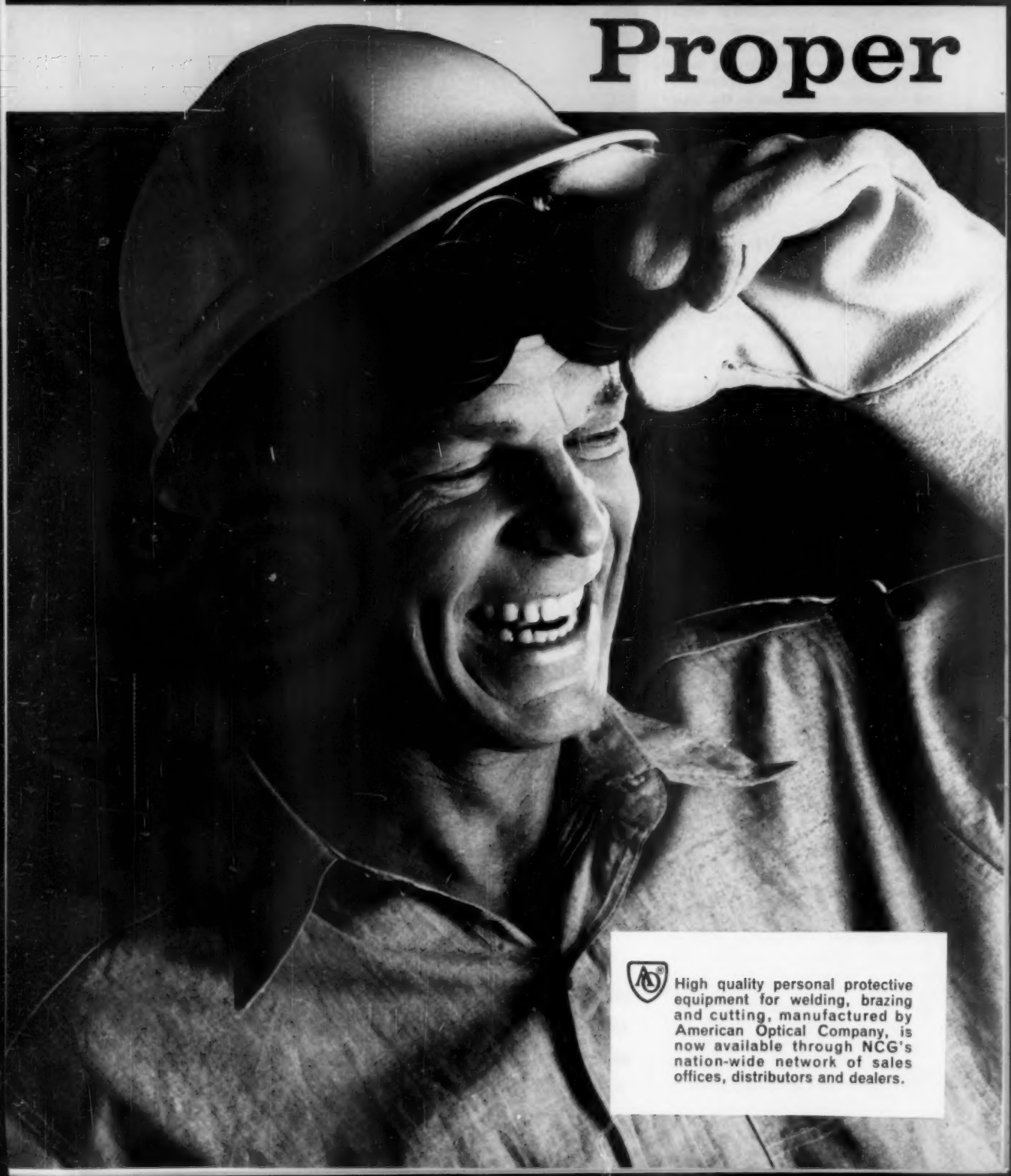
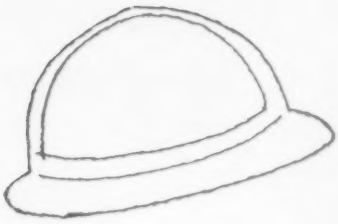
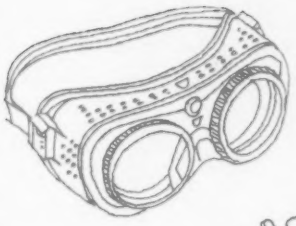
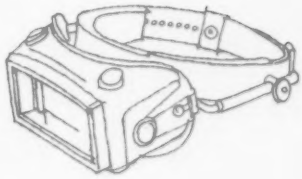
Proper



High quality personal protective equipment for welding, brazing and cutting, manufactured by American Optical Company, is now available through NCG's nation-wide network of sales offices, distributors and dealers.

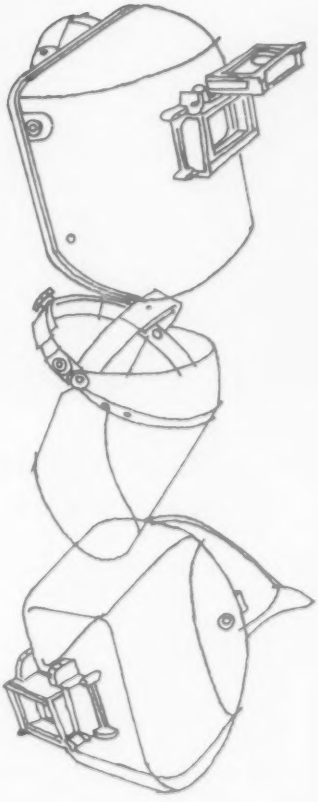






protection

keeps me happy



No one wants an accident—but just in case—*proper* protection, can prevent painful, costly injuries that often cause serious disabilities. Insurance does help, but no matter how much money is received as compensation, it is small return for the permanent damage that could have been avoided.

Your working skills and general well-being must be carefully protected. *Just any old* kind of protection won't do. Different jobs require different kinds of protection. The proper kind of protection for your welding, brazing and cutting jobs is available from your nearby NCG distributor or dealer. Send today for NCG Catalog N-177-E-1M.

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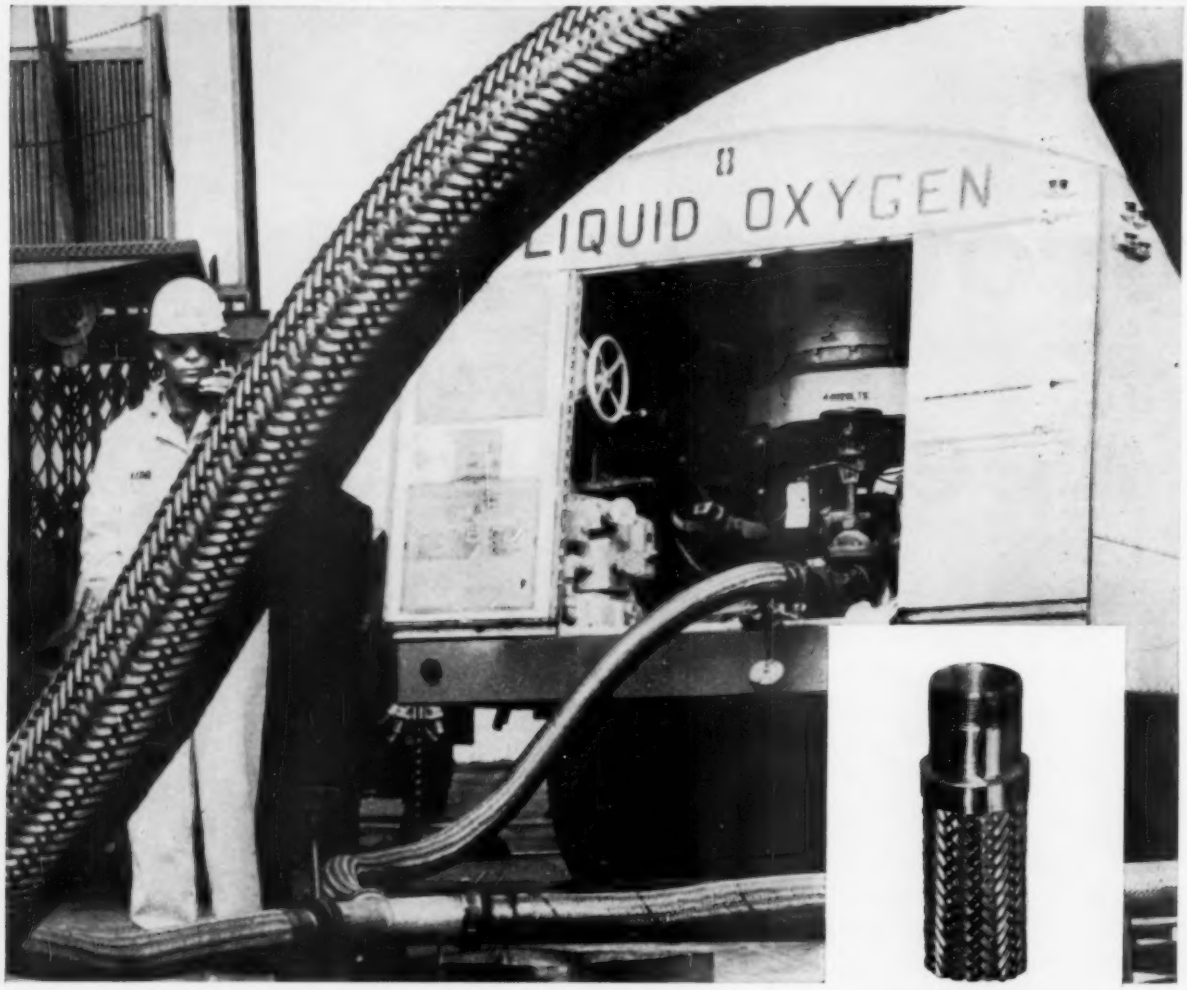
3½ inch I.D. Anaconda flexible metal hose lines are shown here transferring liquid oxygen to Army missile. Brazed metal hose-to-fitting connections are made with Handy & Harman brazing alloys.



Handy & Harman Brazed Connections Withstand Thermal Shock From Liquid Oxygen . . . Time After Time

It is hard to think of a single more punishing test for a metal joint than the nearly instantaneous plunge from approximately 100° F to –297.4° F experienced by these brazed metal hose connections. Yet they take it time and again – and come back for more.

This is part of an assembly employing Type 321 stainless steel flexible hose made by Anaconda Metal Hose to transfer liquid oxygen to Jupiter missiles at the Redstone Arsenal. Fittings are stainless steel, integrally bonded to the hose by Handy & Harman brazing alloys—EASY-FLO and EASY-FLO 35 with Handy Flux. The reasons for using Handy & Harman brazing alloys here make good fabricating sense no matter what the job. First, they provide strong, integral joints that remain strong, ductile and resistant to vibration and shock even to liquid oxygen temperatures and pressures where many metals become brittle. Secondly, they allowed Anaconda to increase burst pressure limits since there is no annealing of the base metal. In addition, they make it possible for Anaconda to perform joining operations with less equipment and less expense in manpower than would otherwise be necessary.

This is only one example of many applications of Handy & Harman brazing products in cryogenics and other fields of engineering to solve critical bonding problems which achieve fast production and operating economies. There's a good chance they will do the same for you. Call or write for further information on how to apply brazing techniques to solve your fabricating problems.

Our Bulletin 20 contains a wealth of data on silver brazing, its range of applications and techniques for securing best results. Write today for your copy.

Your No. 1 Source of Supply and Authority on Precious Metal Alloys

HANDY & HARMAN
850 Third Ave. New York 22, N. Y.

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Welding Research

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SUPPLEMENT TO THE WELDING JOURNAL, NOVEMBER 1961

Argon-Shielded Alternating Current Metal-Arc Welding

Emissive coatings are applied to standard welding wires to permit the welding of both carbon and stainless steel using alternating current

BY C. R. SIBLEY

ABSTRACT. There are three characteristics of a direct-current arc which are, under some circumstances, undesirable for welding. These characteristics can be avoided by using an alternating, instead of a direct-current arc.

The direct-current arc characteristics which cause difficulty in welding are as follows:

1. A direct-current argon-shielded arc is usually connected for reverse polarity which makes the work piece the cathode or hotter arc terminal. Thus, the weld pool becomes very fluid, making it difficult to weld carbon and stainless steel in other than the flat position. With a stable alternating-current argon-shielded arc the work piece is the cathode, or hotter arc terminal, only half the time; even during this time the cathode heating effect may actually be lower than for the direct-current arc. This change in heat balance with alternating current produces a cooler weld pool which makes it easier to weld carbon and stainless steel in other than the flat position.

2. An undesirable characteristic of the direct-current arc shielded with argon is its tendency to wander and produce undercutting along the edges of the weld. Oxygen additions to argon stabilize the arc and reduce the cathode area on the work piece, thus tending to eliminate undercut. An undesirable side effect of the oxygen addition is the oxidation of some alloying elements during welding. A stable alternating-current arc shielded with argon does not produce undercut and oxygen additions are not required to aid arc stability.

3. A direct-current arc is deflected by residual magnetic fields in the plates being welded and by the motor action generated from the flow of welding current. Strong arc-blow forces can deflect the metal droplets in transfer across the arc to produce spatter and poor bead shape. An alternating-current arc is as equally affected by residual magnetic fields as is the direct-current arc. It is, however, less sensitive to deflection by motor action since eddy currents are produced and reduce the deflecting fields formed in the vicinity of the arc. The net effect of the eddy current action is to reduce the deflection of the arc when alternating-current power is used.

In order to obtain a stable spatter-free alternating-current arc in argon with conventional low-open-circuit voltage welding transformers, proper electron emission characteristics must be provided to prevent the loss of a conductive path as the welding current passes through zero. Compounds of rubidium and cesium, when coated uniformly on bare welding wire, provide sufficient electron emission to make the alternating-current arc shielded with argon completely stable without the need for high open-circuit-voltage or superimposed high-frequency sparks.

A uniform emissive coating can be applied to low-carbon and stainless-steel welding wires by a *strand-dip*, *batch-dip* or *spray process*. Regardless of the method used, the coating must be uniform and continuous along the entire length of welding wire. Low-carbon- and stainless-steel welding wires of 0.020, 0.030, 0.035, 0.045 and 0.062 in. diam were emissive coated with a cesium-compound solution to develop stable alternating-current argon-shielded arcs.

To determine the range of application possible with these emissive-coated welding wires, fillet, lap and butt welds were made in material thicknesses between 0.035 and 1.0 in. Most of the welding was done manually with a push-type wire feeder and a 500 amp welding transformer having a maximum open-circuit-voltage of 80 v. In addition to this power source, tests were run using a 600 amp, constant-voltage transformer with a maximum open-circuit-voltage of 30 v. This power source did not produce a stable arc, so it was not possible to use it in welding tests.

From the completed deposits in carbon and stainless steel, it was possible to obtain the tensile properties of the weld metal as well as the properties of completed weld joints. Guided bend test data, in the thinner material thickness, provided a means of evaluating the fusion and ductility of the welded joints. Certain deposits were tested in impact at low temperature. A shielding gas of argon was found completely suitable for alternating-current arc welding of all stainless steels. This gas is recommended for those materials where alloy losses must be kept to a minimum. For alternating-current arc welding of carbon steels argon–oxygen or argon–carbon dioxide mixtures were found completely satisfactory.

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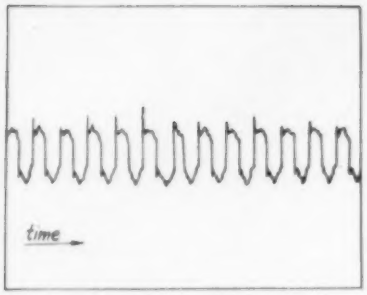


Standard alternating-current arc welding—80 open-circuit volts with drooping voltage characteristic, 500 amp, rating, single phase. Measured value of arc voltage—22 v

Constant-voltage power transformer tapped at 22 v, 600 amp rating, single phase. Measured value of arc voltage—22 v. Voltage and current characteristics are shown

Fig. 1—Alternating-current arc oscillograms for welding wires emissive-coated with cesium compound. Argon shielding—35 cfh

Welding with an alternating-current arc makes the gas metal-arc process more applicable to the joining of thinner carbon and stainless steels. In addition to making good appearing deposits, it was observed that relatively little plate distortion resulted from full-penetration, alternating-current welds on unrestrained sheets as thin as 0.062 in.

Introduction

The gas metal-arc welding process was patented as a reverse-polarity, direct-current welding process.[1] For this reason it is most often thought of as a reverse-polarity welding process. In its first commercial application, the process was applied to the welding of aluminum and aluminum alloys with argon and helium shielding. The process found considerable acceptance for the fabrication of these metals. When gas metal-arc welding was applied to carbon and stainless steels, it was found that argon shielding was not completely satisfactory. Deposits were often irregular in shape, and undercutting was a problem. Additions of oxygen to argon proved satisfactory in overcoming the arc instability, and the resultant deposits were uniformly shaped without undercutting in both carbon and stainless steel. Today the use of premixed argon-oxygen shielding gas for the gas metal-arc welding of carbon and stainless steel is almost universal. The oxygen in the shielding gas does present some problems, which were not associated with argon shielding. The oxidation reaction of oxygen reduces the amount of silicon and manganese in the weld metal; this may result in porosity if excessive amounts of oxygen are added. Low-carbon-steel welding wires that develop sound weld metal with oxygen additions of 1 to 5% are commercially available in a variety of wire sizes. In addition to the favorable reaction on the reverse-polarity direct-current arc, the oxygen addition also stabilizes the straight-polarity direct-current arc. For this stabilization, at least 3% oxygen is required to reduce the drop size and minimize spatter. The commercialization of straight-polarity steel welding with argon-oxygen shielding gas mixtures has not gained appreciable importance; the gas metal-arc process is still basically a reverse-polarity direct-current welding tool.

It has been well known in the covered-electrode industry that certain chemical compounds are capable of stabilizing a welding arc. The oxides of calcium, titanium and iron, plus compounds of sodium and potassium are most capable for this purpose. It has also been found that certain elements, or compounds of such elements, can be used to influence arc stability, heat balance, and metal-transfer characteristics in gas metal-arc process. The successful development of arc stabilizing agents for this process was obtained through the use of emissive-agent compounds. The use of these emissive-agent compounds for both straight-polarity direct- and alternating-current arcs in the gas-shielded, metal-arc process has been patented.[2] The laboratory work which led to this development has been discussed in some detail by Lesnewich.[3] One example of process work involving the use of emissive agents for the gas metal-arc process with argon shielding, using multiple direct- and alternating-current arcs for welded overlays, has been discussed by Felmley.[4] The process controls that can be exercised through the proper use of emissive agents in gas-shielded, metal-arc welding have been discussed by Lesnewich.[5]

More recently, development work has been directed toward the use of emissive agents to obtain a spatter-free metal transfer in carbon dioxide shielding. This work involved both the development of a suitable welding wire analysis and a suitable emissive-agent compound for the coating. Cushman[6] discussed the results of laboratory work required to develop a welding wire and emissive-agent coating for spatter-free carbon dioxide welding. These developments were patented, and an emissive-coated, low-carbon-steel welding wire for spatter-free metal transfer in carbon dioxide is now commercially feasible.[7]

The purpose of this paper is to disclose the present commercial development of alternating-current, gas metal-arc welding. This development extends the gas metal-arc process since, through its eleven years of commercialization, it has not used alternating-current power. One of the paramount advantages of alternating-current power over direct-current power is the reduction of magnetic arc blow. Another advantage is that the emissive agent is capable of producing complete arc stability in a shielding gas of argon. The absence of oxygen in the shielding gas is desirous when welding the stabilized grades of stainless steel and certain other stainless or nickel alloys where low alloy losses from the welding wire are required. An equipment advantage is that an alternating-current power source is relatively simple in construction and inexpensive. Commerical coating methods were developed for applying emissive agents to standard welding wire compositions of both low-carbon and stainless steel. Process data have been compiled to illustrate the potential application of this alternating-current, gas metal-arc welding process.

Procedure

To determine the usability of alternating-current power with the gas metal-arc welding process, a number of standard low-carbon-and stainless-steel welding wires and emissive-agent compounds had to be studied. In addition, methods for applying the emissive agents to the welding wire surface had to be studied. Most of the work involved the use of commercially available welding wire from standard spools of approximately 25 lb each. Small coils were made from these spools which were dipped in a solution containing the emissive-agent compound. Some low-carbon-steel wire was drawn (from 0.072 to 0.062 in. diam) to evaluate spray-coating of emissive agents directly to the wire surface as it left the drawing die.

Table 1—Types of Welding Wires and Coating Methods

Wire Type	Wire size, in.	Nominal composition, wt. % C	Mn	P	S	Si	Ni	Cr	Ti	Al	Emissive-agent coating method
E308L stainless steel	0.062	0.03	1.75	0.025	0.03	0.42	10.25	21.0	...	..	Batch-dipping of small coils and strand-dipping of large coils[a]
E308L stainless steel	0.045	Same as above									Same as above
E308 stainless steel	0.020	0.08	1.75	0.025	0.03	0.42	10.25	21.0	...	..	Batch-dipping of small coils
E308 stainless steel	0.035	Same as above									Strand-dipping of large coils
E321 stainless steel	0.045	0.08	1.75	0.025	0.03	0.42	9.75	19.5	11XC	0.02	Batch-dipping of small coils
Low-carbon steel, copper-flashed and bare	0.062	0.10	1.10	0.025	0.025	0.50	...	..	...	..	Batch-dipping of small coils and spray-coating during wire drawing operation[a]
Low-carbon steel, copper-flashed	0.045	Same as above									Batch-dipping of small coils
Low-carbon steel, copper-flashed	0.030	Same as above									Same as above

[a] Small coils were 2 to 5 lb; large coils were 25 to 50 lb; coils for drawing were 50 to 100 lb.

Some stainless-steel welding wire was emissive-agent coated by a commercial strand-dip method capable of handling large coils of welding wire. A summary of the types of welding wire and coating methods used is shown in Table 1.

After coating, the wires of Table 1 were submitted for welding tests to determine their usability with alternating-current power. The power source used for these welding tests was a standard alternating-current power source having a maximum open-circuit-voltage of 80 v. Its output characteristic was a drooping-voltage-type. This welding unit had a 500 amp rating and operated on single-phase alternating-current power. In addition to this standard power source, a few tests were made using a constant-voltage power transformer having a 600 amp rating and operating on single-phase power. This power transformer could be tapped from 20 to 30 v which is in the range of useful arc voltage for alternating-current argon-shielded arcs. Oscillograms of the alternating-current arc voltage obtained with the standard alternating-current power source and the arc voltage and current obtained with the power transformer are shown in Fig. 1. The complete arc stability that was obtained with the standard alternating-current power source is shown at the left of Fig. 1. With the constant-voltage single-phase power transformer, the arc was completely unstable as shown in the oscillogram at the right of Fig. 1. The results obtained with the standard alternating-current power source were completely satisfactory, so this power source was used for all the test work.

Results

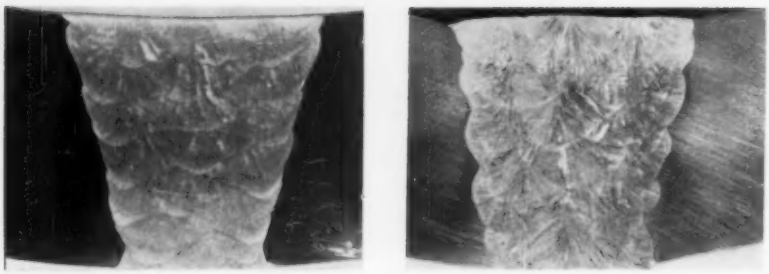
Stainless-steel Weldments

The tensile properties of stainless-steel weld metal deposited with alternating-current power are shown in Table 2 for three types of stainless-steel welding wires. A deposit made with E308L welding wire using direct-current, reverse-polarity power is shown at the right of Table 2. The tabulated tensile-test-values for the alternating-current deposits show that good strength and excellent ductility are obtained with these three types of stainless-steel weld metal. A comparison of the tensile properties of E308L weld metal deposited with alternating- and direct-current power show that comparable values were obtained. However, the Charpy impact strength is considerably higher for the alternating-current deposit than for the direct-current deposit. This variation in impact strength at −100° F testing temperature is believed to be caused by the difference in structure of these two weld metals.

In Fig. 2 a macrographic comparison is made of the E308L weld metal deposited with alternating-current and direct-current power. The weld metal deposited with alternating current does not have a columnar structure like the weld metal deposited with direct current. The etching time on the alternating-current deposit was prolonged beyond the time used on the direct-current deposit in an attempt to clearly define the macrostructure.

Table 2—Stainless-steel Weld-metal Tensile and Impact Properties Obtained from All-weld Metal Deposits (0.505-tensile specimens; Charpy-V notch specimens)

Variable	Alternating-current power			Direct-current R-P power
Shielding gas	Argon	Argon	Argon	99% A + 1% O_2
Welding wire size, in.	0.062	0.045	0.045	0.045
Welding wire type	E308	E321	E308L	E308L
Tensile strength, psi	87,500	97,000	88,800	85,750
Yield strength, psi	67,000	71,000	67,600	65,100
Elongation in 2 in., %	38	45	46	40
Reduction in area, %	58	68	66	64
Fracture type	Cup-cone	Cup-cone	Shear	Shear
Impact strength at −100° F, ft-lb	...	...	100, 97, 96	77, 76, 58
Hardness, Rb scale	...	...	96	95
Arc current, amp	320	280	290	290
Arc voltage, v	30	30	22	30
No. of passes	16	20	21	18



AC argon shielding. Electrolytic etch—30 sec

DCRP 99% A + 1% O_2 shielding. Electrolytic etch—5 sec

Fig. 2—Photomacrographs of E308L stainless-steel weld metal deposited with alternating-current and direct-current power (0.045 in. diam type E308L welding wire)

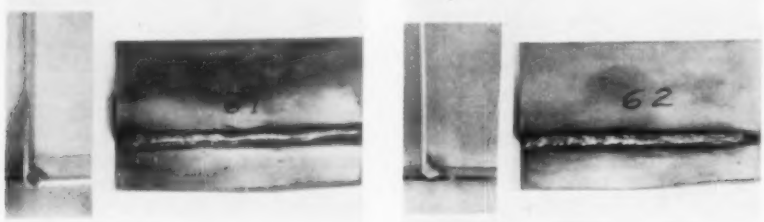
At no time up to 30 sec did a coarse dendritic macrostructure appear. This etching behaviour suggests that the alternating-current deposit etched more uniformly, because it was more homogenous than the direct-current deposit. The combination of more uniform grain size and less segregation in the alternating-current deposit should enhance the low-temperature impact strength of this weld metal.

The mechanical properties of manual alternating-current deposits in Type 304 stainless-steel sheet are shown in Table 3. The welding conditions used for these weldments were selected as optimum by the manual operator and are shown at the bottom of the table. The sheet thicknesses were 0.062, 0.093 and 0.125 in. Three tests were conducted in each thickness. The bend test was made using a bend radius of three times the sheet thickness in all cases. The one root-bend test failure in the 0.125 in. thick sheet was caused by a lack-of-fusion at the edge of the specimen.

The reduced section transverse tensile test data of Table 3 show that consistently high strength can be obtained in welded joints made in the above three thicknesses of Type 304 stainless steel. The variance in tensile strength for the 0.062 in. thick sheet was due to the fact that an average sheet thickness value was used in the tensile strength calculation. Since the welds were ground to remove the weld reinforcement, the thickness at the weld may have been a lower value than that used in the calculation. These tensile strength data also show that an E308 welding wire deposits weld metal of about 86,000 psi. This value was below the tensile strength of the 0.062 and 0.093 in. sheets and above the tensile strength of the 0.125 in. sheet. The double lap-fillet-type tensile-test data show that, in sheet above 0.062 in., the shear strength of the welds is greater than the strength of the sheet, causing failure to occur in the sheet. Welds similar to those shown in Table 3 were made in 0.035 in. thick stainless-steel sheet. However, this thickness could not be welded successfully with the 0.035 in. diam welding wire, because the minimum current values for a stable arc caused occasional burn-through in the sheet. It can be welded with 0.020 in. diam welding wire but no test specimens were made of these welds.

Manual fillet welds were made in 0.062 and 0.093 in. thick Type 304 stainless-steel sheet with an E308 stainless-steel welding wire of 0.035 in. diam. These fillet welds were made in the horizontal position and in two vertical-down positions. In one case, the fillet joint was in the vertical plane (called, in this paper, *a 90 deg. vertical-down fillet weld*). In the other vertical fillet position, the joint was in a plane 45 deg. from the horizontal and sloping away from the weldor. This joint is here called *a 45 deg. vertical-down fillet weld.* Typical views and cross-sections of horizontal and 45 deg. vertical-down fillet welds in 0.062 and 0.093 in. Type 304 stainless-steel sheets are illustrated in Figs. 3 and 4. By varying the gun-to-work-distance and the gun angle, the operator was able to change the values of current and voltage a certain amount as shown in Fig. 4.

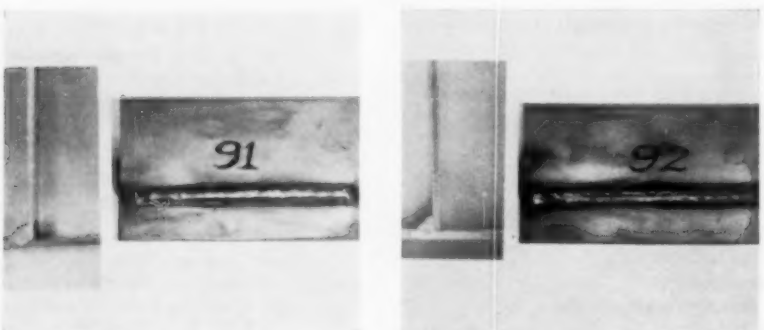
Additional manual fillet welds were made in the 90 deg. vertical-down and overhead positions with equivalent ease of operation and without changing the wire feed speed or power supply settings from those used to make the horizontal and 45 deg. vertical-down welds. Since these fillet welds were made at



Horizontal fillet 190 amp, 17.5 v 18 ipm welding speed

45 deg vertical-down fillet, 190 amp, 17.5 v, 18 ipm welding speed

Fig. 3—Manual fillet welds in 0.062 in. Type 304 stainless-steel sheet. (0.035-in. diam E308 welding wire emissive-coated with cesium compound.) Argon shielding—35 cfh; alternating-current power



Horizontal fillet, 230 amp, 17 v, 20 ipm welding speed

45 deg vertical-down fillet, 215 amp, 18 v, 20 ipm welding speed

Fig. 4—Manual fillet welds in 0.093 in. Type 304 stainless-steel sheet. (0.035 in. diam E308 welding wire emissive-coated with cesium compound.) Argon shielding—35 cfh; alternating-current power

relatively high welding speed, very little plate distortion occurred even in the 0.062 in. thick sheet. Similar welds in this thickness of stainless-steel sheet made with reverse-polarity direct-current or the tungsten-arc process cause considerably more plate distortion.

Shielding Gas

The shielding gas used for all stainless-steel weldments made with alternating-current power was argon. This gas provided adequate shielding for the welding arc, and the resultant deposit was clean and well-shaped. Sufficient arc-cleaning action at the work piece is provided with alternating-current power to completely remove surface films or contaminants from the plate surfaces being welded. Completely sound stainless-steel deposits were made on very dirty or oiled plates and sheets. Since the weld deposits with argon shielding were well-shaped and fused, this gas is recommended for all stainless-steel welding with alternating-current power.

Argon was found suitable for shielding carbon-steel welds in sheet material up to 0.125 in. thick. Argon-shielded deposits in carbon steel above 0.125 in. thick tended to be highly convex and narrow with excessive weld reinforcement and a steep toe angle. To modify the reinforcement, additions of oxygen and carbon dioxide were made to argon to determine their effect on bead and fillet-weld shape. Small additions of oxygen to argon showed some improvement in widening and flattening fillet and bead welds. However, additions of carbon dioxide to argon were found to be more beneficial in producing flat, well-shaped deposits. In addition to improving the reinforcement shape of the deposits, carbon dioxide additions to argon increased the weld area below the plate surface. With additions of 10 and 25% carbon dioxide to argon, it was possible to deposit completely sound bead welds at arc lengths of 1/8 and 1/4 in.

For general carbon-steel welding with alternating-current power, mixtures of 99% argon + 1% oxygen or 75% argon + 25% carbon dioxide are recommended as the best shielding gases. Carbon-steel sheet material up to 0.125 in. thick can be welded with argon, but even here it is felt that oxygen or carbon dioxide additives would improve the deposit shape.

Low-carbon-steel Weldments

The tensile properties of low-carbon-steel weld metal, deposited with alternating-current power are illustrated in Table 4. The shielding gas compositions used for these low-carbon-steel deposits were argon with a 1% oxygen addition and argon with a 25% carbon dioxide addition. Both of these gas mixtures are available commercially and are widely used for low-carbon-steel welding applications. Using the same welding wire, the argon-oxygen shielded deposit gave higher strength and lower ductility than the argon-carbon dioxide shielded deposit. This is the expected result, since a greater loss of manganese and silicon should occur with the argon-carbon dioxide shielded deposit. Due to its higher alloy content, the bare low-carbon-steel welding wire deposit shielded by an argon-oxygen mixture developed the highest tensile and yield strengths with low values of ductility. The tensile and yield strength values of low-carbon-steel weld metal, as shown in Table 4, are sensitive to the oxygen content of the shielding gas. Thus, with a typical low-carbon-steel welding wire it is possible to deposit weld metal having a

Table 3—Mechanical Properties and Welding Conditions for Type 304 Stainless-steel Sheet Weldments Made Manually with Alternating-current Power (0.035 in. diam E308 welding wire emissive-coated with cesium compound; argon shielding—35 cfh)

Sheet thickness, in.→	0.062			0.093			0.125		
Test no.→	1	2	3	1	2	3	1	2	3
Bend test:									
Face, degree	180	180	180	180	180	180	180	180	180
Root, degree	180	180	180	180	180	180	100	180	180
Rad. of bend, in.	3/16	3/16	3/16	9/32	9/32	9/32	3/8	2/8	3/8
Failures	None	None	None	None	None	None	Root	None	None
Red. sect. trans. ten. test:									
Tensile strength, psi	90,200	86,200	85,700	87,800	85,400	86,080	78,100	78,100	78,700
Location of failure	Weld	Weld	Weld	Weld	Weld	Weld	Sheet	Sheet	Sheet
Double lap-fillet tensile test:									
Tensile strength, psi	85,400	92,100	93,000	89,400	88,300	89,300	75,600	76,400	76,200
Location of failure	At edge of weld	Sheet	At edge of weld	Sheet	Sheet	Sheet	Sheet	Sheet	Sheet
Welding conditions:									
Arc current, amp	180	180	180	205	205	205	225	225	225
Arc voltage, v	18	18	18	18	18	18	19	19	19
Welding speed, ipm	Butt-30, Lap-24			Butt-25, Lap-20			Butt-20, Lap-16		

Table 4—Low-carbon-steel Weld-metal Tensile Properties Obtained from All-weld-metal Deposits (0.505-tensile specimens; alternating-current power)

Variable	0.062 in. low-carbon steel, copper-flashed wire		0.062 in. low-carbon steel, bare wire
Shielding gas	99% A + 1% O_2	75% A + 25% CO_2	99% A + 1% O
Gas flow, cfh	35	40	35
Tensile strength, psi	78,000	72,000	82,900
Yield strength, psi	68,250	60,200	72,500
Elongation in 2 in., %	18	21	16
Reduction in area, %	38	55	30.5
Fracture type	Shear	Cup-cone	Shear
Hardness, Rb scale	83	78	86
Arc current, amp	350	380	350
Arc voltage, v	23	30.5	23
Wire chemistry, wt., %			
C	0.08	0.08	0.12
Mn	1.03	1.03	1.30
Si	0.40	0.40	0.60

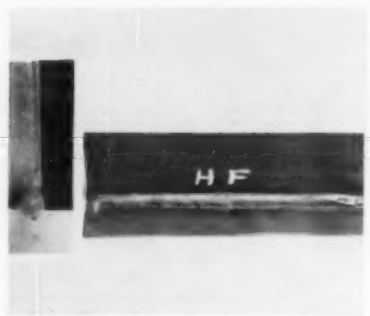
yield strength as high as 68,000 psi. or as low as 60,000 psi. by varying the shielding gas composition. The low-carbon-steel welding wire used in these tests contained sufficient manganese and silicon to retain enough of these elements in the weld metal to suppress porosity, even with a 25% carbon dioxide addition to argon.

The mechanical properties of horizontal butt weldments made in carbon-steel sheet, with alternating-current power are shown in Table 5. These weldments were made manually in 0.062 and 0.125 in. thick sheet. Bend and reduced-section transverse tensile specimens were machined from the weldments. The bend tests were completely satisfactory except for one root-bend specimen which developed a flaw greater than $^1/_8$ in. at 90 deg. bend angle. Tensile strengths equal to that of the steel sheet were obtained in both thicknesses. The fusion-line flaws in the tensile specimens did not open until after considerable yielding had taken place. Failure started at the flaws and ran into the sheets, indicating that the weld metal was tough and not notch-sensitive. The welding conditions shown at the bottom of Table 5 are those selected by the operator as satisfactory for making repeated welds without difficulty.

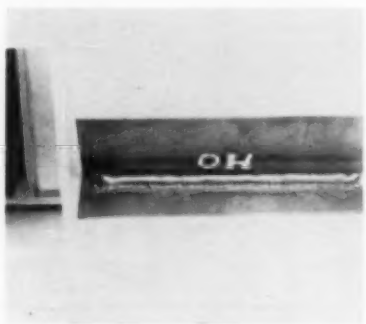
Table 5—Mechanical Properties and Welding Conditions for Carbon-steel Sheet Weldments Made Manually with Alternating-current Power (0.030-in. diam low-carbon-steel welding wire emissive-coated with cesium compound; argon shielding—35 cfh)

Sheet thickness, in.→	0.062			0.125		
Test no.→	1	2	3	1	2	3
Bend test:						
Face, degree	180	180	180	180	180	180
Root, degree	180	180	180	180	180	90
Rad. of bend, in.	$^3/_{16}$	$^3/_{16}$	$^3/_{16}$	$^3/_8$	$^3/_8$	$^3/_8$
Failures	None	None	None	None	None	Root
Red. sect. trans. ten. test:						
Tensile str., psi	58,700	59,800	No test	48,700	49,100	No test
Location of fracture	Fusion-line and sheet	Sheet		Fusion-line and sheet	Sheet	
Welding conditions:						
Arc current, amps	120	120	120	185	185	185
Arc voltage, v	14.5	14.5	14.5	18	18	18
Welding speed, ipm	12	12	12	12	12	12
Joint and position	Butt, horizontal			Butt, horizontal		
Joint preparation	Square-edge			Square-edge		
Root opening, in.	Zero			0.045		

Manual fillet welds were made in 0.062 and 0.125 in. thick carbon-steel sheets with an 0.030 in. diam emissive-coated low-carbon-steel welding wire and alternating-current power. In Fig. 5 a horizontal and an overhead fillet weld in 0.062 in. thick steel sheet are shown. In Fig. 6, a horizontal and 45 deg. vertical-down fillet weld are shown in 0.125 in. thick steel sheet. These manual fillet welds are characteristic of those that can be made in carbon-steel sheets within the thickness range of 0.062 to 0.125 in. The welding conditions are tabulated for these fillet welds to show that, for each thickness, the same conditions can be used for fillet welds in all positions.

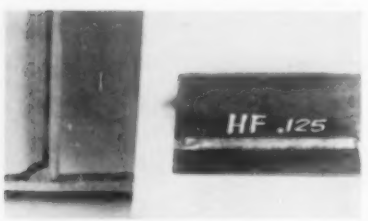


Horizontal fillet, 160 amp, 16 v, 330 ipm wire feed rate, 14 ipm welding speed

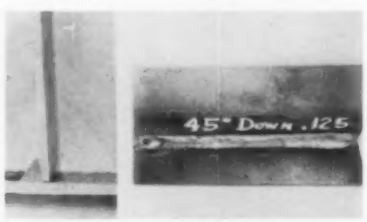


Overhead fillet, 160 amp, 16 v, 330 ipm wire feed rate, 18 ipm welding speed

Fig. 5—Manual fillet welds in 0.062 in. carbon-steel sheet. (0.030-in. diam low-carbon-steel welding wire emissive-coated with cesium compound.) Argon shielding—35 cfh; alternating-current power



Horizontal fillet, 240 amp, 21 v, 220 ipm wire feed rate, 16 ipm welding speed



45 deg vertical-down fillet, 240 amp, 21 v, 220 ipm wire feed rate, 18 ipm welding speed

Fig. 6—Manual fillet welds in 0.125-in. carbon-steel sheet. (0.030-in. diam low-carbon-steel welding wire emissive-coated with cesium compound.) Argon shielding—35 cfh; alternating current power

Automatic butt welds in $^1/_2$ and $^3/_4$ in. thick carbon-steel plates were made using shielding gases of argon and argon plus 10 and 25% carbon dioxide. An 0.062 in. diam, emissive-coated low-carbon-steel welding wire and alternating current power were used for all the welds in both thicknesses. These automatic butt welds were made by positioning a welding gun above a moving work piece. The types of welds and welding variables are summarized in Table 6. A representative cross-sectional view of each butt weld described in Table 6 is shown in Fig. 7. The data of Table 6 and Fig. 7 show that, in $^1/_2$ in. thick carbon-steel plate, two-pass butt welds which are completely fused and sound can be made. The data shown for the argon-shielded weld compared to that shown for the argon–carbon dioxide shielded welds point out the more complete fusion and less porosity obtained when carbon dioxide was added to argon.

In the cross-sectional views of Fig. 7, broader fusion is shown for

Table 6—Automatic Butt Welds in 1/2 and 3/4 in. Carbon-steel Plate (0.062 in. diam low-carbon-steel welding wire emissive-coated with cesium compound; alternating-current power)

Joint No.[a]	Shielding gas, at 40 cfh	Procedure	Welding Conditions: Pass no.	Amp	V	Travel speed, ipm	Results: Macro check	Results: X-ray
1	Argon	One pass each side, no back-up. No backside chipping or grinding	1	400	22	12	Incomplete fusion, porosity	Lack-of-fusion, scattered porosity
			2	400	22.5	12		
2	90% A + 10% CO_2	Same as above	1	395	25	12	Complete fusion, sound	Complete fusion, no porosity
			2	395	25	12		
3	75% A + 25% CO_2	Same as above	1	360	31	12	Complete fusion, sound	Complete fusion, porosity at one end
			2	360	30.5	12		
4	90% A + 10% CO_2	Same as above	1	400	25.5	12	Complete fusion, sound	Complete fusion, no porosity
			2	400	26	12		
5	75% A + 25% CO_2	Same as above	1	425	32	12	Complete fusion, sound	Complete fusion, no porosity
			2	410	32	12		
6	75% A + 25% CO_2	Same as above	1	450	33.5	13	Complete fusion, sound	Scattered lack-of-fusion, no porosity
			2	450	32	13		

[a] Joint designs correspond to joint numbers as follows:

argon-carbon dioxide shielded deposits than was obtained with argon shielding. This broader fusion, particularly at the extreme depth of penetration, makes the interfusion of the deposits at the plate centerline more certain. The convexity and and reinforcement of the argon-shielded deposit, even with an open gap and beveled edges, is considered excessive for this type of joint. With both 10 and 25% carbon dioxide in argon, it was possible to make a square-butt weld in 1/2 in. thick plate without any joint preparation except flame cutting and tack welding. A small root opening produced less weld reinforcement and where possible this joint design should be used. The lack-of-fusion in the butt weld made in 3/4 in. thick carbon-steel plate resulted from a displacement of the penetration off the weld seam during the second pass, due to a change in the wire cast. When the wire cast was adjusted to make the penetration directly into the joint, a completely-fused weld in 3/4 in. thick plate could be made.

Discussion

The application of emissive agents to the surface of low-carbon-and stainless-steel welding wires in controlled amounts was easily accomplished. It can be done in a number of ways. Three methods are described in this paper—*batch-dip coating*, *strand-dip coating* and *spray-coating*. The commercial emissive-coating method used for preparing alternating-current welding wire is the strand-dip method. This method is capable of processing large quantities of wire at a rapid rate; since each element of wire length is dipped in the emissive-agent solution it can be coated uniformly.

The results obtained from deposits made in stainless- and carbon-steel sheet and plate show that the alternating-current gas metal-arc process is capable of producing sound and consistent welded joints in both these materials. The joint types included in this paper are limited, but their intention is to point out the potential use of this welding process for the fabrication of stainless- and carbon-steel weldments. This alternating-current welding process offers, for the first time, the ability to use a conventional, argon-type spray-transfer arc for all-position welding of a given thickness of stainless- or carbon-steel sheet material without changing the preset values of the wire feed speed and the power supply. With direct-current power it is often necessary to change the welding conditions when the position of the joint varies. To weld sheet in all positions with direct-current power

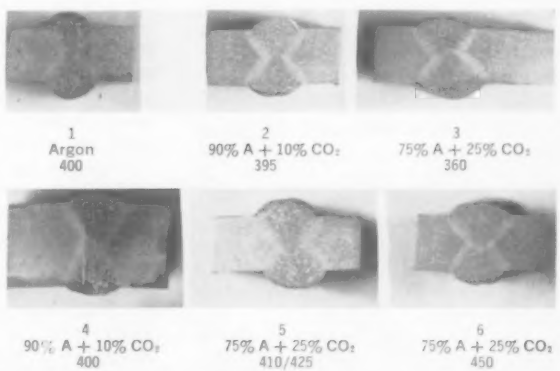

Joint no. 1 2 3
Shielding gas Argon 90% A + 10% CO2 75% A + 25% CO2
Current, amp 400 395 360
Joint no. 4 5 6
Shielding gas 90% A + 10% CO2 75% A + 25% CO2 75% A + 25% CO2
Current, amp 400 410/425 450

Fig. 7—Cross-sectional views of automatic butt welds in 1/2 and 3/4-in. carbon-steel plate. (0.062-in. diam low carbon-steel welding wire emissive-coated with cesium compound.) Alternating-current power

usually requires changes in shielding gas type, current value and mode of transfer.

A pronounced absence of magnetic arc blow was observed while welding the square-butt joints in carbon-steel plate with alternating-current power. Previous attempts to make such welds with the gas-shielded process, using direct-current reverse-polarity power, usually resulted in heavy arc blow, particularly at the ends of the joint. This arc blow with direct current caused undercutting and poor bead shape as well as porosity and spatter. With alternating-current power, the square-butt deposits were continuous and uniform and free of spatter from end to end. This same freedom from magnetic arc blow obtained in these small carbon-steel plates may not be found in welding massive sections which could retain strong magnetic fields. However, as mentioned previously, with alternating-current power there is a general reduction in the arc-blow forces which deflect the arc.

Conclusions

The gas metal-arc welding process has been extended to incorporate the use of alternating-current power through the successful application of emissive-agent coatings to standard stainless- and low-carbon-steel welding wires. For stainless-steel welding, the use of emissive-agent coated welding wire and alternating-current power obviates the use of argon-oxygen mixtures and thus reduces alloy losses from wire to weld metal. This higher transfer efficiency should make the gas-shielded process more attractive for the welding of stabilized grades of stainless steel and those containing aluminum. For carbon-steel welding, either argon or mixtures of argon and oxygen or argon and carbon dioxide may be used as the shielding gas. Argon is applicable to the welding of carbon-steel sheet material, whereas the argon-oxygen or argon-carbon dioxide mixture is better applied to the welding of heavier gauge material. A relatively new gas mixture containing 75% argon and 25% carbon dioxide should be used for square-butt joints in heavy steel plates to obtain better fusion characteristics.

Commerical coating methods are capable of applying controlled amounts of emissive agents to standard welding wires of both stainless and low-carbon steel. Tests have shown that the shelf-life of emissive-agent coated welding wire is very good. As long as the wire surface does not come in contact with water, the emissive-agent coating should remain unchanged.

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EUROPEAN WELDING RESEARCH

By Gerard E. Claussen

EAST GERMANY

Most of the April 1961 issue of *Zis Mitteilungen* is concerned with CO_2 welding. By December 1960 there were 300 semi-automatic CO_2 units in East Germany, mainly converted submerged arc units. It was expected that the number would be increased to 1000 by the end of 1961. Analyses of CO, NO_2, Mn, Zn, Cr, Ni, Cv and SiO_2 in the atmosphere breathed by the welder gave no indication of unhygienic conditions, provided normal safety measures were taken.

- CO_2 welds in St52 steel contained 0.10 C, 0.96 Mn, 0.47 Si, and had higher impact value at −76° F than weld metal deposited by 6027 and 6024 electrodes and by submerged arc. A low-hydrogen electrode deposited metal of almost the same composition but with better impact value.

Porosity in CO_2 welds was absent with electrodes containing 1.34 Mn, 0.81 Si or 2.10 Mn, 0.28 Si. Addition of up to 80% oxygen to CO_2 increased the penetration by exothermic reaction and by reducing the viscosity of the weld metal. Carbon and silicon are burned out before manganese which is believed to be the element mainly responsible for prevention of porosity. Transfer coefficients of Mn and Si were much higher from base metal to weld metal than from electrode to weld.

A survey of commercial CO_2 showed that purity was adequate, the water content averaging only 100 mg per 100 l. Nevertheless, since cylinders are cleaned only once in five years, it was recommended that cylinders for welding purposes be stored separately.

A small CO_2 welding unit has been developed for automatically welding staybolts into locomotive boilers.

Gas tungsten-arc welding with argon, 8 cfh, and a thoriated tungsten electrode 0.039-in. diam was selected for joining austenitic stainless steel sheet 0.010 to 0.018 in. thick to itself and to mill steel. Only 3 to 8 amp was used for the thinnest sheet. The electrode was ground to a sharp point and was held in a pencil torch.

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USSR

Avtomaticheskaya Svarka for March 1961 contains the following articles:

- In ultrasonic welding copper and duralumin sheet, the shear strength in pounds increased with time of welding, but strength in pounds per square inch of welded area was constant. It was concluded that the process consisted of breakdown of contaminant film by friction followed by interatomic adhesion.
- An electron-optical image converter for radiography is described.
- The effect of carbon and phosphorus on the Mesnager impact value of single-pass submerged arc welds in $^5/_8$-in. plate was determined for 55 weld metal compositions. The welds were made at 920–950 amp, 36–38 v., 20 ipm with MnO-SiO_2 flux. At −22° F at least 27 ft-lb was attained by all weld metals falling below a curve in the carbon vs phosphorus plot that passed through 0.04 C, 0.08 P; 0.16 C, 0.08 P; 0.24 C, 0.04 P.
- Wrinkled deposits in gas metal-

(*Continued on page 502-s*)

Welding 12% Chromium Martensitic Stainless Steels

Using either the shielded metal-arc or submerged-arc process, welding is readily carried out under conditions of high restraint and complete freedom from cracking is obtained with 500–700° F preheat

BY C. H. KREISCHER, J. COTHREN AND A. E. NEAR

SYNOPSIS. Utilization of nuclear energy has posed a number of materials problems, both in the development of new materials and in the utilization of existing ones. In this latter category, 12% chromium stainless steels are quite useful.

Although 12% chromium materials have been used extensively in welded construction for many applications, little or no data are available on the elevated temperature stress rupture properties of such welds. Furthermore, many welding procedures recommend that martensitic 12% chromium steels be post-weld heat treated before they have cooled below the welding preheat temperature. This practice is considered to be not only unnecessary but also, in certain cases, to be technically undesirable.

Consequently, work was undertaken to deposit Type 410 submerged-arc and shielded metal-arc welds in heavily restrained sections of a martensitic 12% chromium stainless steel casting. These welds were allowed to air cool to room temperature before being heat treated. Room temperature tensile and bend tests and elevated temperature stress-rupture tests were conducted on both types of welded joints in both the stress-relieved and normalized and tempered conditions. Good joint strengths and ductilities were obtained with no evidence of cracking as a result of cooling the as-welded material to room temperature.

The second part of this paper describes the satisfactory results obtained in deposition of austenitic stainless steel weld overlays on Type 410 components for nuclear systems. A procedure involving cooling the welds to room temperature before post-weld heat treatment has been used with complete success on a number of different heats of 410 steel.

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Paper presented at the AWS 42nd Annual Meeting held in New York, N. Y., during April 17–21, 1961. Authors' Note: "When this paper was written the authors included information and expressed opinions believed to be correct and reliable. Because of the constant advance of technical knowledge, the widely differing conditions of possible specific application, and the possibility of misapplication, any application of the contents of this paper must be at the sole discretion and responsibility of the user."

Introduction

During the past five to ten years remarkable advances have been made in the utilization of nuclear energy. One factor that has contributed to these advances has been the successful development of new metal alloys and the suitable application and fabrication of existing alloys. In this latter category, 12% chromium martensitic stainless steels have been quite useful.

The combination of good mechanical properties at temperatures up to 1050° F along with good corrosion and erosion resistance to the relatively moist steam encountered in nuclear powered steam turbines makes 12% chromium stainless steels desirable materials for certain components of these turbines. Likewise, these steels have suitable properties for components exposed to the primary coolant where good strength, good corrosion and erosion resistance to water, and suitable magnetic characteristics are required. For both applications, it is necessary that the material be welded in restrained sections. Type 410 stainless steel satisfactorily meets all of these requirements.

Although the martensitic stainless steels have been welded for many years and recommended welding procedures for them are readily available in a variety of references,[1–6] it was desirable that additional work be conducted to further evaluate welding procedures and resultant weld joint properties for the steels to be used for these applications. In particular it was of interest to know the elevated temperature stress rupture properties of these welded joints and to further investigate the necessity for post-weld heat treating them immediately after welding.

Most references, including at least one prepared by the authors' company,[7] have recommended that post-weld stress relieving be done before the weld has cooled below the preheat temperature. It is considered, however, that in many instances these recommended procedures are merely holdovers from ones that were established many years ago.

In the light of improved metallurgical understanding of fracture mechanisms and the resultant need for more exacting joint properties, it is questioned if the old procedures produce optimum results. Indeed, it is even questioned whether detrimental effects might result in some instances if the older recommendations are followed.

The first part of this paper, therefore, describes the results of an investigation conducted to evaluate the room and elevated temperature properties of Type 410 welds which were deposited in a martensitic 12% chromium cast steel and allowed to cool to room temperature before being heat-treated. The second part of the paper deals with the application of these results to the weld overlaying of Type 410 stainless steel components.

Weld Evaluation Program

Materials

Consideration of materials for the steam turbine application indicated that a 12% chromium stainless steel with additions of nickel and molybdenum would have the desired properties for this application and would be superior to Type 410. Consequently, a large casting of the modified alloy was obtained for use in this program. The casting was obtained and welded in the normalized and tempered condition.

Table 1—Chemical Compositions (%)

	C	Cr	Mn	Mo	Ni	Si	P	S	N
Casting	0.13	11.4	1.29	0.67	1.71	0.43	0.035	0.008	0.013
E410-15 shielded-metal-arc weld	0.08	12.75	0.36	0.44	0.23	0.32	0.023	0.019	...
ER410 submerged-arc weld	0.06	11.38	0.74	0.04	0.40	0.65	0.020	0.010	...

The chemical composition of the casting is shown in Table 1 along with the chemical compositions of both the submerged-arc and shielded-metal-arc welds that were subsequently deposited in grooves machined in the casting. Both welds were made with conventional Type 410 stainless steel electrodes, AWS-ASTM ER410 and AWS-ASTM E410-15.

Welding Procedure

Groove Preparation. A number of 1 in. deep Vee grooves with $^3/_8$ in. root openings and sidewalls inclined 20 deg. from the vertical were machined in material removed from the casting. This material was in the form of several blocks which were approximately 4 in. thick, 7 in. long, and of varying widths ranging from 7 to 14 in. One groove was machined in the top face of each block as shown in Fig. 1. After those grooves were submerged-arc welded and prior to post-weld heat treatment, a similar groove was machined on the opposite face of each of the blocks. These grooves were subsequently shielded-metal-arc welded.

Welding Conditions. The submerged-arc and shielded-metal-arc welding procedures are described below:

Submerged-Arc Welds

Electrode—$^5/_{64}$ in. diam Type 410 bare wire, AWS-ASTM ER410.
Flux—size 12 x 65 fused, neutral submerged-arc welding flux.
Current—300–400 amp.
Arc volts—25–35 v.
Polarity—straight (electrode negative).
Travel speed—12 ipm.
Preheat—550° F.
Maximum interpass—750° F.

The first two or three passes in the roots of the submerged-arc welded grooves were deposited with the minimum values of current and arc voltage after which the maximum listed values were used for completion of the welds.

Upon completion of the submerged-arc welds, the blocks were cooled to room temperature in still air and the grooves for shielded-metal-arc welding were then machined on the opposite face of the blocks. These grooves were then welded according to the conditions shown below using electrodes that were thoroughly baked prior to welding.

Shielded-Metal-Arc Welds

Electrode—$^3/_{16}$ in. diam type 410 lime coated, AWS-ASTM E410–15.
Current—170–200 amp.
Arc volts—22–24 v.
Polarity—Reverse (electrode positive).
Preheat—550° F.
Maximum interpass—750° F.

The first layer and every other layer of weld thereafter in all of the grooves were magnetic particle tested during welding, but no defects were detected.

Post-Weld Heat Treatment

After each groove was welded, the block containing it was cooled to room temperature. Upon completion of all welding, half of the blocks were normalized and tempered while the other half were merely stress relieved. Thereby, both submerged-arc and shielded-metal-arc welds in both heat treated conditions were available for subsequent evaluation.

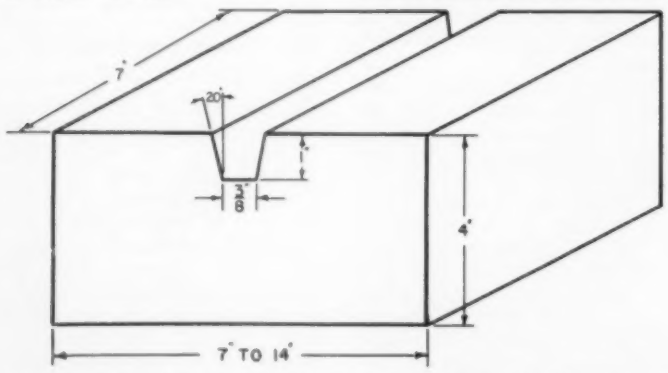


Fig. 1—Geometry and dimensions of block prepared for restrained groove welds

Table 2—Weld Joint Hardnesses

	Average Rockwell A hardness		
	Weld	HAZ[a]	Base material
Metal-arc—stress relieved	55½	61	59
Submerged-arc—stress relieved	55½	59½	60
Metal-arc—normalized and tempered	53½	...	61½
Submerged-arc—normalized and tempered	56½	...	61½

[a] HAZ—Heat-affected Zone.

The normalize and temper heat treatment consisted of heating the welded blocks to a temperature of 1850° F and holding at temperature for 8 hr, fast air cooling to a temperature below 200° F, reheating to 1300° F for a 20 hr tempering treatment, and then air cooling to room temperature.

Because of the lack of tempering data for this particular alloy, studies were conducted to determine the heat treatment needed to adequately temper the weld heat-affected zone. Based on these results, the post-weld stress relief heat treatment consisted of heating the welded blocks to 1350° F after they had cooled to room temperature and then holding them at that temperature for 8 hr followed by air cooling.

Test Results

Hardness and Microstrucure. A transverse section was removed from each of the heat treated welds and used for Rockwell A hardness measurements and macroscopic examination. Results of the hardness measurements are shown in Table 2, and the appearance of typical macrosec-

Submerged arc weld

Manual metal arc weld

Fig. 2—Macrosections of stress relieved welds showing Rockwell A hardness. X 2 (Reduced about 60% on reproduction)

tions is shown in Fig. 2. It can be seen that the post-weld stress relief heat treatment adequately tempered the weld heat-affected zones to hardnesses comparable to the base material. Perhaps more significant however, was the fact that both the post-weld stress relief and the normalize-and-temper heat treatments tempered the welds to hardnesses significantly lower than the base metal hardness. These differences in hardness between the welds and base material resulted from the higher carbon and alloy content of the base material which made it harder and more resistant to tempering than the Type 410 weld. Macroscopic examination of these samples did not reveal any cracks.

Sections were removed from each of the macro samples and were prepared for metallographic examination. Careful examination of these specimens, with particular attention devoted to the weld heat-affected zone, did not reveal any cracks. Typical microstructures of the weld fusion zones are shown in Figs. 3 and 4. As can be seen in these photomicrographs, the shielded-metal-arc welds contained considerable amounts of delta ferrite, whereas there was none in the submerged-arc welds. This difference in ferrite content between the metal-arc and submerged-arc welds is undoubtedly due to the higher chromium and molybdenum and lower nickel and manganese contents of the metal-arc welds as compared to the submerged-arc weld composition. It is also likely that the cooling rate of the metal-arc welds was faster than that of the submerged-arc welds through the temperature range in which delta ferrite transforms to austenite. Consequently, less time was available for equilibrium amounts of austenite to be formed in the metal-arc welds. Thus both the chemical composition and the cooling rate of the shielded-metal-arc welds (as they solidified and cooled) promoted the retention of ferrite in their microstructures.

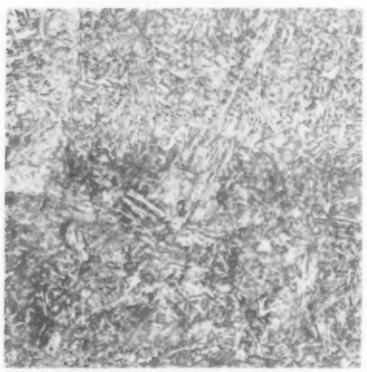
It is also of interest to note that the stress relieved shielded-metal-arc weld contained significantly more ferrite than the normalized and tempered weld. Since the subcritical stress relief had no effect on changing the amount and distribution of ferrite in the weld microstructure, the ferrite content of the stress relieved weld is the same as that present in the as welded condition. During the austenitizing portion of the normalize-and-temper heat treatment, however, a portion of the ferrite present in the weld receiving this heat treatment was transformed to austenite. Subsequently this austenite transformed to martensite. The fact that a small amount of ferrite was still present in the microstructure of the normalized and tempered metal-arc weld indicates that the chemical composition and the temperature at which the weld was austenitized were such as to place it within a two phase region where a small amount of ferrite was in equilibrium with the austenite.

Room Temperature Strength and Ductility. Room temperature mechanical properties of both the shielded-metal-arc and submerged-arc welded grooves in both heat treated conditions were determined with conventional transverse tensile and bend specimens. The specimens tabulated below were removed from each of the four welded grooves.

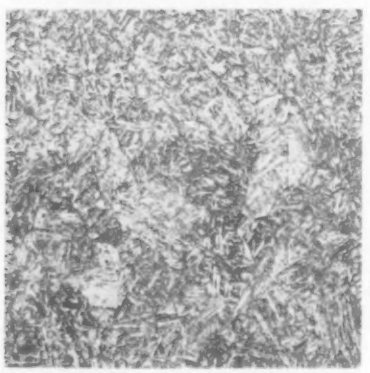
No.	Description
2	0.505 in. diam transverse tensile bars
2	Face bends
4	Guided side bends
3	Guided longitudinal bends

All specimens with the exception of the guided longitudinal bends are conventional ones which need no description. The longitudinal bend samples, which were 4 in. wide, 5 in. long, and $\frac{1}{4}$ in. thick, were removed parallel to the face of the weld with the weld running longitudinally through the center of them. The specimens were removed successively—one beneath the other, from the face of the weld, from an intermediate position, and from the root of the weld.

The results of tests conducted on these specimens are shown in Table 3. The typical appearance of these specimens after testing is shown in Fig. 5. As indicated in Table 3, several specimens were not tested since they contained repair welds or shrink in the base material near the test welds. Unfortunate as it was that these samples had to be discarded, the occurrence of shrink is not uncommon in large castings weighing several tons and having complex shapes such as the casting from which the test material was obtained. Likewise it is normal foundry practice to repair weld such regions.

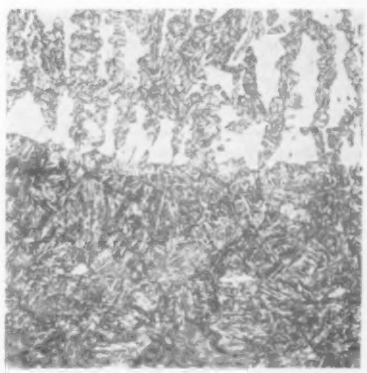


Stress relieved

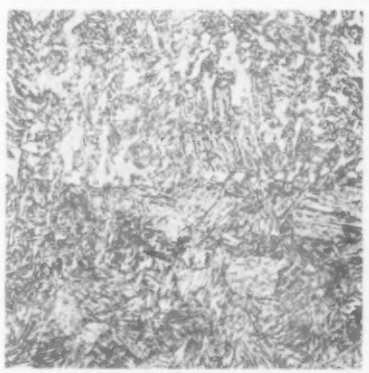


Normalized and tempered

Fig. 3—Microstructure of submerged-arc weld and heat affected zone. Vilella's etch. X 100



Stress relieved



Normalized and tempered

Fig. 4—Microstructure of manual metal-arc weld and heat affected zone. Vilella's etch. X 100

It will be noted that no failures occurred within the weld or weld heat-affected zone in the guided side bends or the guided longitudinal bends. The only defects revealed by these specimens occurred in one of the guided side bends, which cracked in regions of the base material containing shrink that was not detected prior to testing. This base metal failure was sufficiently far from the weld to be entirely unaffected by it and was definitely the result of shrink in the casting. Complete freedom from transverse cracking was clearly demonstrated by the longitudinal bends. In contrast to the guided bend tests, however, all of the tensile and face bend tests failed within the weld deposits.

It is not surprising that the tensile specimens failed in the welds, since they were tempered much softer and were consequently weaker than the adjacent base material. However, the tensile strengths and ductilities obtained with these specimens were normal for Type 410 weld metal tempered to the hardness of these specimens. Due to the comparative softness of the welds, virtually all of the deformation occurred within the weld metal rather than uniformly over the gage length. Therefore, the elongation values reported for the 2 in. gage lengths, of which only about $^1/_2$ in. was weld metal, are considerably lower than would have been obtained with all-weld-metal test specimens. Consequently, the measured reduction in area of these specimens provides a more reliable indication of the weld ductility. As shown in Table 3, these values are more than adequate.

Although the face bends failed in the welds, all of the welds exhibited remarkable ductility. Elongations measured across the welded joints varied from a minimum value of 59% to a maximum of 89%. Again the comparatively hard base material adjacent to the welds forced virtually all of the deformation to occur within the weld metal. Consequently, the capacity of the weld to yield, good as it was, was exceeded and specimen failure resulted.

Analysis of the room temperature test results reveals that satisfactory results are obtained with welds deposited by either process and given either post-weld heat treatment. Although the normalized and tempered submerged-arc weld had the highest tensile strength and face bend ductility, there is no apparent explanation for this observation.

Elevated Temperature Properties. Elevated temperature stress rupture tests were also conducted on transverse specimens removed from each of the welds in each heat treated condition. These tests were conducted on standard smooth rupture bars having a gage diameter of 0.253 in. with the weld located in the center of the 2 in. gage length. All of the test bars were radiographed, etched and liquid dye penetrant inspected. No defects or repair welded regions were revealed. The results of these tests are tabulated in Table 4 and are plotted on the Larson-Miller parameter basis in Fig. 6.

Analysis of the rupture test re-

Table 3—Room Temperature Mechanical Properties

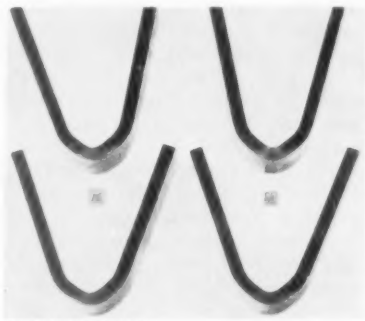
Tensile properties

	Ultimate tensile, psi	0.02% yield, psi	Elongation in 2 in., %	Reduction area, %	Break location
Metal-arc—stress relieved	91,500	50,000	16	53	Weld
	91,000	47,500	15	54	Weld
Metal-arc—normalized and tempered	92,500	50,000	9	30	Weld
	94,000	52,000	14	54	Weld
Submerged-arc—stress relieved	92,000	57,000	17	58	Weld
	84,500	50,000	24	65	Base
Submerged-arc—normalized and tempered	101,000	65,000	14	54	Weld
	102,500	70,000	14	53	Weld

Bend test results

	—Shielded-metal-arc welds—		— Submerged-arc welds —	
	Stress relieved	Normalized and tempered	Stress relieved	Normalized and tempered
Guided side bends	2 satisfactory 2 not tested[a]	1 satisfactory 1 cracked in base met. shrink 2 not tested[a]	3 satisfactory 1 not tested[a]	4 satisfactory
Guided longitudinal bends	3 satisfactory	3 satisfactory	3 satisfactory	3 satisfactory
Face bends	Broke in weld—65% elongation Broke in weld—59% elongation	Broke in weld—59% elongation Broke in weld—75% elongation	2 not tested[a]	Broke in weld—89% elongation Broke in weld—72% elongation

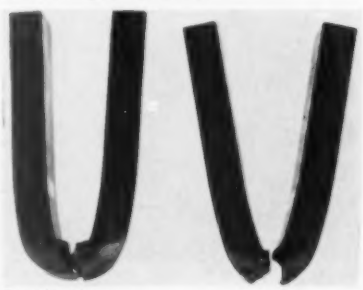
[a] Specimens not tested contained base metal shrink and/or casting repair welds.



Guided side bends

Transverse tensiles

Guided longitudinal bends



Face bends

Fig. 5—Typical appearance of welded tensile and bend specimens after testing

Table 4—Elevated Temperature Stress Rupture Properties

Temperature, °F	Stress, ksi	Time, hr	Elongation, %	Reduction area, %	Parameter*	Break location
Stress-relieved shielded-metal-arc weld						
1000	27	142	19	85	39.6	Fusion line
1050	22	89	33.6	89	40.7	Fusion line
1100	18	67	26.4	89	41.8	Base metal
1150	13	164	18.8	87	43.8	Weld
1200	10	178	16.3	79	45.3	Weld
1250	8	209	15.9	79	46.7	Weld
Normalized and tempered shielded-metal-arc weld						
1000	26	513	16.6	66	40.5	Weld
1050	20	370	20.7	88	41.7	Fusion line
1100	16	255	9.3	28	42.7	Weld
1200	12	37	5.2	22	44.1	Weld
1200	10	96	5.7	16	44.8	Weld
1250	8	90	5.3	19	46.1	Weld
Stress-relieved submerged-arc weld						
1000	25	212	17.6	69	39.9	Weld
1050	20	178	23.2	85	41.2	Base metal
1100	17	63	14	52	41.8	Weld
1150	12	205	8.2	28	43.9	Weld
1200	10	62	7	28	44.4	Weld
1250	7	65	16.5	28	45.8	Fusion line
Normalized and tempered submerged-arc weld						
1050	27	47	18	82	40.3	Weld
1200	20	3	17.6	90	42.2	...
1150	14	130	17	80	43.6	Weld
1200	11	94	14.1	77	44.8	Weld
1200	8	590	11.8	61	46.1	Weld

* Parameter = $T (25 + \log t) \times 10^{-3}$; T = °Rankine, t = hr.

sults indicates that, although there were differences in strength between the various welds, these differences were quite small. The stress relieved submerged-arc weld had lower strength than the others, while the normalized and tempered submerged-arc weld tended to be the strongest; the two metal-arc welds were intermediate in strength. It is doubtful, however, that there is any real significance to the relative strengths of the welds as indicated by these tests. The differences in strength are so small that they doubtless are all within the scatter-band that would be established if a number of welds of the same type and heat treatment were tested. Also no logical explanation to describe the observed differences in strength was evident. It is interesting to note though that the ferrite content of the shielded-metal-arc welds did not impair their rupture strengths or ductilities, at least relative to the submerged-arc welds. In fact the stress relieved shielded-metal-arc weld, which had the greatest ferrite content, had the highest rupture strength at parameter values beyond 100,000 hr at 1050° F and the highest ductilities over the full range of test conditions.

General Discussion

An interesting aspect of this investigation is that specimens removed from four different welds deposited with Type 410 electrode in a hardenable 12% chromium cast alloy were completely free from cracks in the weld and weld heat-affected zone. This fact in itself is not outstanding except that, contrary to most recommended welding procedures, all of these welds were cooled to room temperature in the as-welded condition. Furthermore, while the submerged-arc welded grooves were at room temperature in the as-welded condition, they were subjected to a considerable amount of mechanical shock. During this time they were moved to another building for additional machining after which they were again preheated, a second groove welded in each, cooled to room temperature, transferred to another building, and finally post-weld heat treated. Since no special precautions were taken to minimize mechanical shocks, these welds had more than ample opportunity to crack. Nevertheless, the test results clearly demonstrated complete freedom from cracks in these restrained welds.

Inasmuch as most welding procedures for hardenable 12% chromium steels recommend that post-weld stress relieving be done before the weld has cooled from the preheat temperature, the reasons for deviating from these procedures might naturally be questioned.

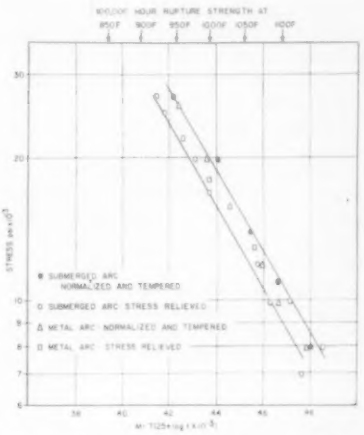

STRESS, psi x 10³
● SUBMERGED ARC NORMALIZED AND TEMPERED
○ SUBMERGED ARC STRESS RELIEVED
△ METAL ARC NORMALIZED AND TEMPERED
□ METAL ARC STRESS RELIEVED

Fig. 6—Transverse rupture strength of 12% chromium stainless steel welds

First, it is considered that many recommended welding procedures for 12% chromium steels are carry-overs from work done many years ago. Until recently, it was believed that martensite was always extremely brittle and crack sensitive. Consequently, it was thought necessary that precautions be taken immediately after welding to avoid the formation and stressing of untempered martensite. In order to accomplish this with 12% chromium materials, it is of course necessary to prevent them from transforming on continuous cooling through the temperature range in which martensite forms. Hence, many recommended welding procedures specified the use of high preheats above the martensite start temperature, followed immediately by a subcritical stress relief during which time isothermal transformation of the austenite to ferrite and carbide occurred.

In recent years, however, metallurigical investigations[8] have revealed that quite contrary to former belief, martensites with 0.15% carbon maximum can have remarkably good properties. A number of constructional low alloys have taken advantage of these observations and at least one of them has demonstrated the capacity to be welded with little or no preheat and no stress relief and to have weld joint properties comparable to the base metal.[9-11] Also the development of high quality low hydrogen type arc-welding electrodes has greatly mini-

mized the likelihood of underbead cracking in martensitic weld-heat-affected zones. Consequently, the formation of martensite in low carbon hardenable 12% chromium steel weldments prior to heat treatment appeared to be unobjectionable.

Furthermore, a substantial risk exists that a procedure of stress relieving before cooling from the preheat temperature may result in the retention of austenite and its subsequent transformation to untempered martensite after such heat treatment.[4, 12] Any untempered martensite would, of course, impair the ductility of the welded joint and could lead to poor service performance. Although untempered martensite has sufficient ductility to withstand stresses of the type and magnitude encountered by welds before they are post-weld heat treated, it is likely to be inadequate to withstand the severe service stresses imposed in many applications. It is possible to adjust the time and temperature of the post-weld stress relief to ensure complete transformation of the austenite, but economical considerations usually lead to the adoption of as short a heat treating cycle as practical to provide reasonable assurance that austenite is not retained. However, chemical variations that occur from heat to heat of material are sufficient to appreciably change the transformation characteristics of some heats. Consequently, complete isothermal transformation may not always be obtained unless the specified heat treatment contains a generous safety factor of several more hours than the time usually required for complete transformation.

Consideration of the transformation characteristics of the 12% chromium steel studied in this investigation revealed that the risk of incomplete transformation in it was quite great unless the weldment was cooled to room temperature prior to stress relieving. The martensite start temperature for this type of material was found to be 530° F, and transformation to martensite was not complete until it had cooled to approximately 200° F. It was further found that isothermal transformation of this material is sluggish. A specimen austenitized and cooled to about 490° F underwent about 20% transformation to martensite. Subsequent heating to 1350° F and holding at that temperature for 6 hr resulted in an additional transformation of only 40%. Consequently, 40% of the austenite remained untransformed at the end of the isothermal treatment. Thus the necessity for cooling welded joints in this material to room temperature to ensure complete transformation to martensite is evident. Only by undesirably long isothermal heat treatments, double tempering, or normalizing and tempering could transformation of any retained austenite be assured if the weldment was not first cooled to room temperature.

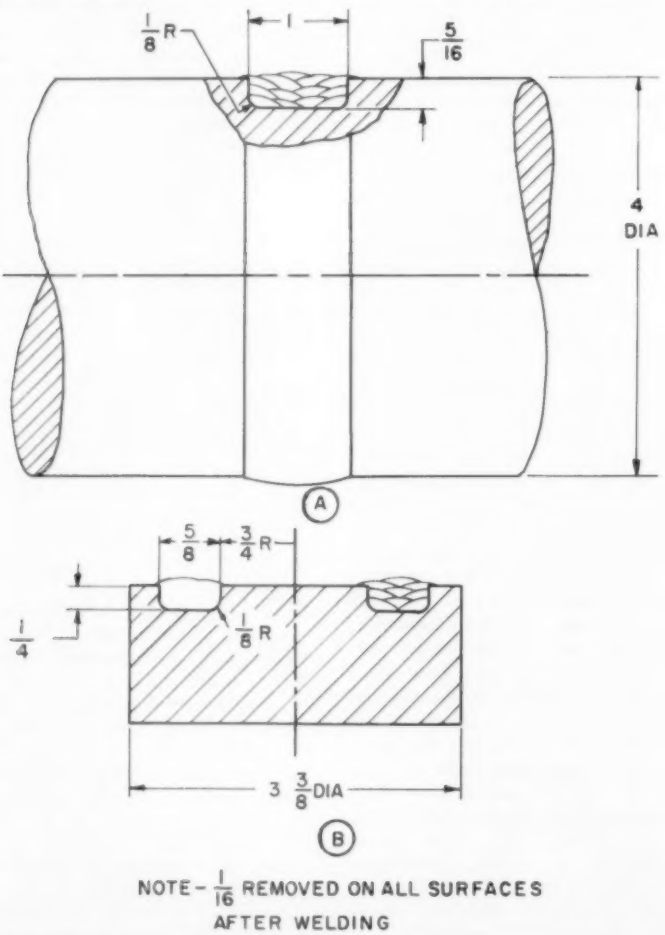


Fig. 7—Typical weld deposited overlay geometries

Furthermore, even if complete isothermal transformation is obtained during post-weld heat treatment, the resultant microstructure and mechanical properties are inferior to those obtained by allowing complete transformation to martensite to occur during continuous cooling followed by tempering.[13] Whereas continuous cooling followed by tempering produces a uniformly fine structure with good strength and ductility, high temperature isothermal transformation produces a much coarser structure which may be quite nonuniform. Consequently, as reported by Kauhausen, *et al.*,[13] isothermal transformation produces considerably lower impact properties than obtained by continuously cooling and tempering.

One other factor that favors the procedure used in this investigation is that it frequently is impractical, uneconomical, or otherwise undesirable, to hold the weldment at preheat temperature until it is post-weld stress relieved. Time, money, effort and scheduling difficulties can usually be saved by the freedom that is provided when a weldment can be cooled before it is heat treated. Furthermore the process control is simplified and more nearly foolproof if the weldment can be cooled prior to stress relieving.

These considerations therefore led to the conclusion that these welded joints not only could be, but also for best results should be cooled to room temperature before post-weld heat treating. The successful results obtained in this investigation, the extensive turbine production experience, and the fabrication ex-

perience with austenitic weld overlays on Type 410 forgings substantiate this contention.

Fabrication Experience—Weld Overlays on Type 410

Design Considerations

Components of water moderated atomic power reactor systems which are exposed to the primary coolant are typically made of, or are surfaced with, Type 304 stainless steel materials, except where for functional reasons Type 304 cannot be used. For example, where magnetic properties are required, Type 410 stainless steel is sometimes used. In this case, the welding of the Type 410 material to Type 304 parts is frequently required at a stage where post-weld heat treatment is not possible. Good practice dictated that the Type 410 material be surfaced with weld deposited austenitic stainless steel material over a sufficient area and with a sufficient thickness to contain the subsequent fabrication weld and its weld heat-affected zone. The forging is then heat treated after the weld-deposited overlay is made so that the later fabrication welds can be made without requiring heat treatment. This technique is also used in some cases for the joining of Type 410 parts used with the forging when heat treatment is not possible after fabrication welding.

Since the likelihood of developing heat affected zone cracks in Type 410 components during austenitic weld overlaying is similar to, and no more severe than, that encountered in the welding program previously described for 12% Cr castings, a similar procedure with respect to post-weld heat treatment was established for these weld overlays.

Welding Procedure and Evaluation

Typical weld overlay geometries of production parts are shown in Fig. 7. Deposition of the austenitic overlay material, AWS-ASTM E310-15, was made with the following electrode sizes and conditions:

Electrode Diameter in.	Welding conditions Amps	Volts-DCRP
1/8	80–95	23–25
5/32	105–130	24–26

The procedure outlined below was followed in welding:

1. Preheat the part to be overlayed within the range 400 to 625° F.
2. Deposit overlay under welding conditions above.
3. Air cool to room temperature.
4. Stress relieve (temper heat-affected zone of Type 410) in range 1250 to 1350° F.
5. Machine to finish dimensions.

Mock-ups for procedure qualification were made to the above procedure. In addition, to evaluate the margin against underbead cracking, two mockups were water quenched from preheat temperature immediately after welding—one quenched in water at 84° F and one in water at 50° F. In all cases the mock-ups were of the type shown in Fig. 7A. All mockups were examined as follows: liquid penetrant and radiographic examination—no evidence of defects of any type; sectioning and metallographic examination—no evidence of underbead cracks in any of the samples; side bends—side bend specimens approximately 1/8 in. thick containing the weld and the heat-affected area removed from the mockups and bent 180 deg around a 1/4 in. mandrel. Specimens taken from all mockups after post-weld heat-treatment bent without cracking in the heat-affected zone.

Table 5—Chemical Compositions (%) for Type 410 Forgings

Heat no.	C	Mn	Si	Cr	Ni	M	P	S	Al	Cu	Sn
61441	0.11	0.42	0.39	12.61	0.24	0.42	0.023	0.010	0.01	0.12	0.025
801632	0.13	0.58	0.32	12.12	0.38	0.05	0.015	0.012	0.01	0.12	0.011
19712	0.13	0.68	0.21	12.00	0.23	0.11	0.019	0.013	0.02	0.07	0.01
50138	0.13	0.46	0.25	12.21	0.19	0.04	0.018	0.015	0.01	...	0.005
04984	0.11	0.67	0.31	11.82	0.34	0.09	0.020	0.005	0.01	0.10	0.020

Production Experience

Several hundred production overlays of the type shown in Fig. 7 have been made using the procedure previously described with complete success. In all cases the overlays and the adjacent base metal were liquid penetrant inspected after post-weld heat-treatment and finish machining. The exposed portion of overlay and the adjacent base metal surface was again liquid penetrant inspected after fabrication welding to the overlay area was completed.

These production welds involved approximately 18 heats of AISI Type 410 supplied by at least 7 different material sources. The overlays were deposited by at least 8 different qualified operators. To date, no cracking has been detected in any of the mockups or production assemblies. The chemical composition of several heats of material which have been used recently are shown in Table 5.

Initial production forgings were overlayed in the annealed condition. Production experience revealed, however, that annealed Type 410 has significantly poorer impact properties than the same material normalized and tempered to the same hardness. Consequently, later forgings were overlayed in the normalized and tempered condition. These results are similar to those reported by Kauhausen[13] where the quenched and tempered structure of 12% chromium welds was observed to have far superior impact properties to those obtained in welds that were isothermally transformed as a result of being stress relieved directly from the welding preheat. These observations further indicate the advisability of cooling 12% chromium welds below the martensite transformation range before they are stress relieved.

Metallurgical Considerations

Consideration of the transformation behavior and other metallurgical characteristics of hardenable 12% chromium stainless steels indicates that, in view of the successful results obtained with the hardenable 12% chromium stainless steel considered in the first part of this paper, there is every reason to expect even less difficulty with Type 410 base metal. A potential source of cracking in 12% chromium stainless steel is the formation of martensite as the weld heat-affected zone cools through the transformation range. However, the actual occurrence of cracking is dependent on a number of factors.

One of the primary factors is the hardness of the martensite that is formed. Generally speaking, the harder the martensite, the more brittle and more susceptible it is to cracking. The hardness of untempered martensite is primarily a function of the carbon content such that the higher the carbon content, the higher the hardness. Type 410 and the hardenable 12% chromium stainless steel casting evaluated in this program both have low carbon contents, i.e., 0.15% maximum. Therefore, from the standpoint of carbon content alone, one should be no more crack sensitive than the other. As de-

scribed subsequently, however, martensitic hardness and crack susceptibility are also influenced by self-tempering characteristics of the alloy.

A second factor which influences crack sensitivity is the rate at which stress is applied to the martensite. In welded joints the rate of stress application is generally dependent on cooling rate. Once again the welding procedures used with both materials were similar so that comparable cooling rates, stress application rates, and cracking tendencies from this factor would result. The fact that mockup samples of Type 410 were water quenched after welding without developing cracks demonstrates the margin of safety that exists when the weldments are uniformly cooled in still air.

Another factor, which influences cracking of martensite, is hydrogen absorption. If the atmosphere surrounding the arc is high in hydrogen, relatively large amounts of it will be absorbed in the austenite while the weld and heat-affected zones are at elevated temperatures. As the weld cools, the solubility for hydrogen decreases rapidly and abruptly decreases when transformation of austenite to martensite occurs. Consequently, any excess hydrogen is rejected from solution and is considered to collect in vacancies, dislocations and other discontinuities as molecular hydrogen which then exerts a high internal gas pressure. The stress generated by this gas pressure along with other weld stresses can lead to cracking of untempered martensite. However, submerged-arc welding or the use of properly dried covered electrodes with low hydrogen type coatings minimizes hydrogen to acceptable levels in the arc atmosphere. Thus, the likelihood of hydrogen absorption and underbead cracking is equally negligible for welded joints in both the 410 and the modified 12% chromium cast steel.

Finally, the temperature range over which martensite formation occurs can have a significant influence on the susceptibility to cracking. In general, the higher the temperature at which the martensite forms the greater is its ductility and resistance to cracking. Not only does the martensite have somewhat greater ductility if it forms at a high temperature, but also it may be partially tempered at and slightly below the temperature at which it forms.[8] This self-tempering or quench tempering, as it is called, improves the notch toughness of the steel and increases its resistance to cracking.

In order for self-tempering to occur, however, the composition of the steel must be such that martensite formation occurs at relatively high temperatures. In the case of Type 410 stainless steel, published data[6,12] indicate that martensite forms on continuous cooling through the temperature range of 675 to 500° F. Since the martensite forms at a reasonably high temperature, it has relatively good initial ductility which is still further improved by subsequent self tempering.

Although the weld heat-affected zone in Type 410 stainless steel is therefore in a relatively ductile condition, the as-welded heat-affected zone in the modified 12% chromium casting was less ductile. The temperature range over which martensite forms in the latter alloy was found to be 530 to 200° F. Thus the martensite that forms is less ductile initially than that which forms in Type 410, and it also is unable to undergo any self tempering. Consequently, the as-welded heat-affected zone in the modified 12% chromium casting should be more crack sensitive than that of 410 stainless steel. Nevertheless, as already reported, absolutely no cracking occurred in the weld heat-affected zone of the modified 12% chromium steel even though it was cooled to room temperature immediately after welding and was subjected to appreciable thermal and mechanical shock prior to tempering. The improved ductility of the weld heat-affected zone in Type 410 stainless steel should provide it with an even greater margin of safety.

Thus the results of this investigation and the production welding experience demonstrate that welded joints in Type 410 and hardenable stainless steels, similar to the 12 Cr alloy investigated in this program, can be satisfactorily air cooled to room temperature before they are post-weld heat treated. Furthermore all the factors considered in this program indicate the desirability of cooling 12% chromium weldments below the martensite formation range prior to post-weld stress relieving in order to obtain optimum properties.

Conclusions

1. Martensitic 12% chromium stainless steels having maximum carbon contents of 0.15% can readily be welded under conditions of high restraint with either the shielded-metal-arc or the submerged-arc welding process.

2. Complete freedom from cracking in the weld and weld heat-affected zone can be obtained in restrained welds deposited at a preheat of 500 to 600° F in Type 410 and hardenable low carbon 12% Cr-Ni-Mo stainless steels even though the weldments are uniformly air-cooled to room temperature immediately after completion of welding.

3. In order to provide the greatest assurance that optimum properties will be obtained, welded joints in these low carbon martensitic stainless steels should be cooled below their M_f temperature before being stress relieved.

4. Type 410 welds deposited with both the shielded-metal-arc and submerged-arc welding processes, and given either an appropriate stress relief or normalize and temper heat treatment, have equally good room temperature tensile and bend properties as well as elevated temperature stress rupture properties.

Acknowledgment

The authors are grateful for the many helpful discussions with R. J. Christoffel and the constructive suggestions of Messrs. R. M. Curran and E. F. Potter. The contribution of metallurgical data related to transformation characteristics of the cast 12 Cr-Ni-Mo alloy by C. D. Walker is also greatly appreciated as are the contributions of co-workers responsible for preparation of welds and test samples, mechanical testing, and preparation of metallographic specimens.

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Advancements in Submerged-Arc Welding of High-Impact Steels

A fused non-alloy bearing, calcium-silicate composition provides superior weld impact properties

BY R. A. KUBLI AND W. B. SHARAV

Introduction

Metal deposited by the submerged-arc welding process has long been recognized as being cleaner and freer from injurious inclusions than metal deposited using covered electrodes. Tensile values are comparable for specific alloy contents. However, impact values provided by submerged-arc weld metal have traditionally been poorer. This situation was exaggerated by the fact that covered-electrode deposits were, by nature of the process, stringer-bead in character whereas sound submerged-arc deposits of much larger size were readily made. Heavy deposits did not have the benefit of the tempering effect of subsequent passes; hence they tended to have poorer impact properties. Nevertheless, the unfavorable comparison of impact properties held even on deposits of equivalent size.

The importance of impact strength was not widely considered until quenched and tempered steels of the T-1 and HY-80 types came into prominence for tanks, structures and naval vessels. These steels provided excellent low temperature impact properties at high yield strength levels and these properties were demanded in welded fabrication. Studies by the Naval Research Laboratories providing data on failures of welded ships in World War II further emphasized the role of impact properties in steel and welds. Here the undesirable situation evolved where the submerged-arc process, having become established among fabricators of vessels and ships, could not be used because it could not provide the impact properties deemed necessary by many authoritative investigators and required by codes. A strong desire to use submerged-arc welding because of familiarity and economy gave the necessary impetus to develop materials and techniques for submerged-arc welding of notch-tough steels.

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Problem of Notch Toughness Plus High Strength

The problem of meeting impact requirements was complicated by the fact that the new steels were not only high in impact strength but high in tensile strength. Weld metal having 90,000—100,000 psi yield strength and 105,000—115,000 psi ultimate tensile strength was required. One steel mill guarantees quenched and tempered steel up to $2^1/_2$ in. thick to have a minimum of 100,000 psi yield strength along with 17% elongation and 50% reduction of area. Charpy values are specified to be 15 ft-lb keyhole at −50° F and 20 ft-lb "V" notch at +10° F.

Submerged-arc welding involves two basic materials: wire and welding composition. In early development work it was assumed (*a*) that, with correct wire chemistry, any standard welding composition would be satisfactory and (*b*) that the composition performed only its well-known functions of protection and arc support. The so-called neutral compositions, which do not add alloying elements, were naturally selected when the alloy was put in the wire. These efforts invariably produced weld metal which met tensile requirements but failed to meet impact requirements. The composition was then regarded as the possible key to obtaining notch toughness.

Composition Development

Objectives

The concept of using the composition as an alloy carrier in combination with an unalloyed wire was useful in developing wire analyses but did not alter the basic problem. The simple inclusion of alloy in the flux was incidental, and satisfactory impact properties were obtained only when the basic carrier composition had the proper characteristics. Under carefully controlled conditions, satisfactory impact properties were obtained with alloy-fortified fluxes. However, this approach was unsatisfactory from a commercial point of view because the results were sensitive to changes in welding conditions, especially voltage.

With this background experience, an objective was formulated as follows:

1. To produce a fused nonalloy-bearing composition capable of providing high-impact properties in submerged-arc weld metal.
2. To maintain, in this composition, the excellent weldability characteristics of general purpose submerged arc welding compositions.
3. To provide alloy wires designed to meet the tensile properties required in steels such as T-1, NAX-TRA, and SSS-100.

Calcium Silicate Systems

It is well known that covered electrodes of the 110–18 type give good impact results, and a submerged-arc composition of this general lime-silica-fluoride type was formulated and weld-tested. The three elements were used in approximately equal amounts and comprised about 60% of the total. When tested with a wire providing approximately 95,000 psi yield strength, Charpy "V" impact values of 65 ft-lb at room temperature were obtained tapering sharply off to 12–15 ft-lb at −50° F. This result was encouraging, and it was decided to investigate the calcium silicate systems further.

Wollastonite is a well known source of CaO and SiO_2 held together in the stoichiometric proportions of 0.93 in the naturally occurring mineral. Initial flux formulations were bonded using approximately 85% wollastonite with

Table 1—Calcium Silicate Welding Compositions

	A Fused	B Bonded	C Bonded	D Fused	E Fused
CaO %	23	30	34	40	44
SiO_2 %	38	43	42	45	41
CaO/SiO_2(R)	0.60	0.70	0.81	0.89	1.08
Total: CaO + SiO_2 %	61	73	76	85	85

certain other elements added to adjust arc characteristics. Mechanical tests obtained with this material were good, but welding action was poor with heavy surface pocking. A low-alloy manganese-molybdenum wire was used to provide approximately 75,000 psi ultimate tensile strength. The improvement in impact properties using this composition was substantial with values ranging from 70 ft-lb at room temperature to 35 ft-lb at −50° F compared to 45 ft-lb and 10 ft-lb at the same temperatures with the best available standard fused submerged-arc welding composition.

It was then decided to duplicate the bonded product as a fused product and simultaneously substitute lime and silica for wollastonite. The substitution was intended to permit varying of the lime-to-silica ratio that was not possible when using wollastonite as the raw material. The original purpose of the substitution was to lower the silicon level which was thought to be detrimental, but the results can be associated with the lime-silica ratio, or basicity, as well as simply a reduction of the total silicon in the weld metal. A second purpose was to lower the silicon level by substituting other compounds without increasing the lime.

Experimental Compositions

A group of compositions was then produced following this program over a period of time with CaO/SiO_2 ratios as shown in Table 1. The ratios obtained vary from a low of 0.60 for composition "A" to 1.08 for "E." Composition "A" is actually a commercial, essentially "neutral," fused composition included for comparison purposes. All the test compositions consisted of 75–85% lime and silica with only such other additives as necessary to adjust melting and arc characteristics. Aside from the commercial fused composition "A," two of the group are bonded materials and two are fused. The immediate improvement noted in going from the bonded to the fused type was complete elimination of surface pocking on the weld deposit. All deposits were sound.

The tensile properties of multipass welds made with the experimental compositions using a 0.5% molybdenum, 1% manganese low-alloy steel wire are shown in Table 2. These values establish that approximately 75,000 psi tensile strength was achieved in all cases. The value obtained with composition "C" is higher by 10,000 psi. This slightly higher value is reflected on impact strength in some of the following data.

Composition Effects

Figure 1 depicts the impact properties obtained in curve form. These are Charpy "V" values. The CaO/SiO_2 ratio for the composition used in each case is shown on the curves. It is to be noted that a striking improvement in impact values results as the ratio increases. At room temperature the fused composition "A" gives about 60 ft-lb compared to over 100 ft-lb for composition "E." At −50° F, composition "A" does not provide the minimum value of 15 ft-lb, whereas composition "E" provides 90 ft-lb. Composition "C" does not completely follow the trend toward improved impact values with increasing CaO/SiO_2 ratios. However, it is only slightly displaced from the trend and experimental error may have played a part in this situation. The welding characteristics of the composition tend to deteriorate as the ratio goes above 1.1 and consequently the "E" composition was selected for further work. The "E" composition has given consistently good welding properties as well as mechanical properties and is readily reproducible in commercial batches.

Table 2—Weld Metal Tensile Properties for Multipass Welds—Stress Relieved, 1% Mn 0.5% Mo Wire

	UTS[a]	YS[a]	El, %	RA, %
A	77	63	27	60
B	73	58	28	67
C	82	63	27	64
D	75	59	25	67
E	73	58	32	72

[a] PSI x 1000

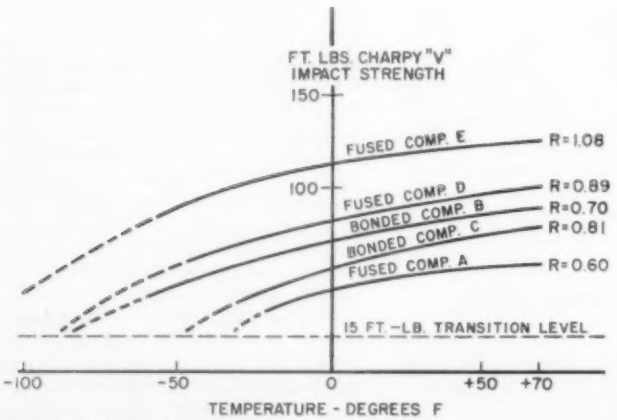


Fig. 1—Weld metal impact curves for multipass welds in stress-relieved condition

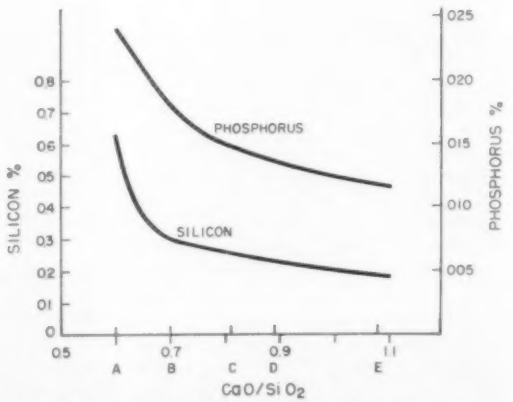


Fig. 2—Weld metal—silicon and phosphorus vs. CaO/SiO_2 ratio

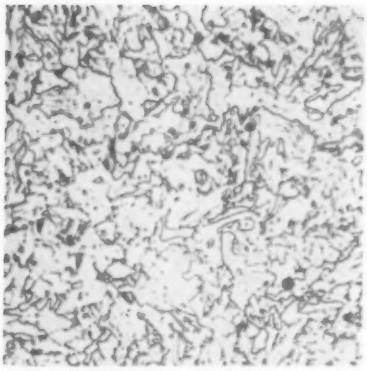


Fig. 3—Weld metal microstructure for Composition A. Nital etch 500X

Fig. 4—Unetched weld metal for Composition A. 500×

Fig. 5—Unetched weld metal for Composition E. 500×

Weld chemistry is shown in Table 3. The chemistry begins to give a clue why impact values improve with an increase in the CaO/SiO_2 ratio, although it does not, of course, explain the mechanism by which the result is achieved. In this chart the strength giving elements, carbon, manganese and molybdenum are shown to the left as a matter of record. Silicon and the impurity elements phosphrous and sulfur are shown to the right and, are of prime interest. The compositions used have been identified again, and it will be remembered that impact properties increase going from "A" to "E." Sulfur does not seem to have an important effect on impact strength, at least up to the maximum values employed. Sulfur values scatter indiscriminately from 0.012 to 0.020 in the welds made with the experimental compositions. Phosphorus and silicon, however, follow a fairly well defined trend. This trend shows that both low silicon and low phosphorus are associated with the best impact values. The trend is interrupted only by the silicon level provided by composition "C," which expectedly should have been lower. Otherwise, phosphorus and silicon values decrease steadily as impact values increase. Plotting the lime/silica ratio of the compositions against the phosphorus and silicon content of the weld metal, as in Fig. 2, shows a very sharp drop in both these elements from that obtained using the commercial fused composition "A." The reduction is not so great as the lime/silica ratio is increased further. The curve for silicon was drawn ignoring the value obtained with the "C" composition. The reduction in silicon content in the weld metal is predictable, since the compositions simply contain less silica as the ratio increases. Reduction in phosphorus apparently follows, but the mechanism by which this is accomplished is not as clear.

The microstructure of welds made with the "A" composition at one extreme and the "E" composition at the other both have the same ferritic structure as shown in Fig. 3. The grain size is smaller than ASTM No. 8. The photomicrograph was actually taken from the weld made with the "A" composition. In the unetched condition, however, the weld metal produced by the "E" composition is noticeably cleaner and freer from inclusions. This composition also provides the best impact strength. The comparison between unetched weld metal deposits is shown in Fig. 4 for composition "A" weld metal and Fig. 5 for composition "E" weld metal. The relative cleanliness of the weld metal combined with small grain size is believed to have significant bearing on the good impact properties obtained with composition "E."

Composition "E" developed in the manner described is usable on boiler-construction steels falling into the ASTM A-300 classification. This classification imposes impact property requirements on several ASTM steels such as A-212 and A-201. Various commercially available welding wires may be used to satisfy the tensile requirement. However, the main objective for the new composition was to permit welding high-yield-strength steels with high-impact properties and this required development of alloy-steel wires.

Table 3—Weld Chemistry (%)—1% Mn 0.5% Mo Wire

	C	Mn	Mo	S	P	Si
A	0.06	1.26	0.44	0.023	0.024	0.63
B	0.07	0.89	0.24	0.020	0.018	0.29
C	...	...	...	0.020	0.014	0.54
D	...	...	...	0.012	0.014	0.27
E	0.07	0.67	0.25	0.021	0.013	0.20

Table 4—Chemistry (%)—Experimental Wires for High Yield Strength Steels

	C	Mn	Mo	Ni	Cr	V	Cu	S	Si	P	Yield Strength, psi SR
HT. 1002	0.07	1.4	0.55	2.6	...	...	0.13	0.005	0.00	0.005	90,000
HT. 1006	0.06	1.4	0.49	2.2	...	0.11	0.25	0.010	0.02	0.015	100,000
HT. 1008	0.17	1.8	0.55	2.7	0.34	...	0.54	0.010	0.15	0.003	120,000
HT. C	0.12	1.8	0.55	2.7	...	...	0.18	0.004	0.05	0.003	115,000
HT. D	0.08	1.8	0.53	2.5	...	...	0.24	0.026	0.07	0.005	100,000

Welding Wire Formulation

Many experiments were made bonding metals to the composition and adding metal oxides to it by fusing for the purpose of establishing weld chemistry necessary to get 100,000 psi yield strength. Welds were made using these compositions with standard low alloy welding wires. These experiments showed that the addition of nickel, molybdenum and manganese could lead to higher tensile strength without impairing the impact strengths provided by the composition. Information on the desirability of limiting silicon and phosphorus was already available from the tests made

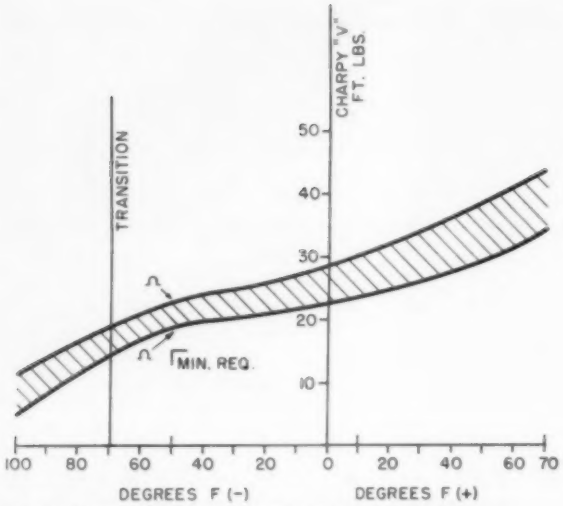


Fig. 6—Charpy "V" notch impact values vs. temperature for stress-relieved weld metal

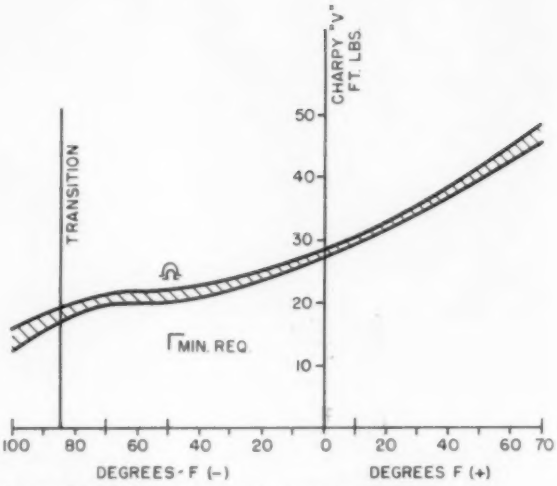
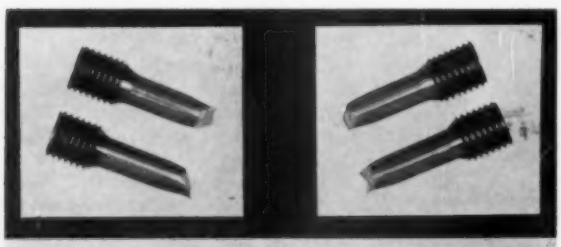


Fig. 7—Charpy "V" impact values vs. temperature for as-welded weld metal

at the lower tensile levels. The desirable amounts of the various elements were then used in the formulation of experimental wires. Some of the significant wires in the group obtained are shown in Table 4 along with the nominal yield strengths obtained. It is apparent that the wires in the group straddle the aim of 100,000 psi yield strength. Wire made from heat 1008 provided 120,000 psi yield strength, which was considered to be too high to resist cracking tendencies in commercial practice.

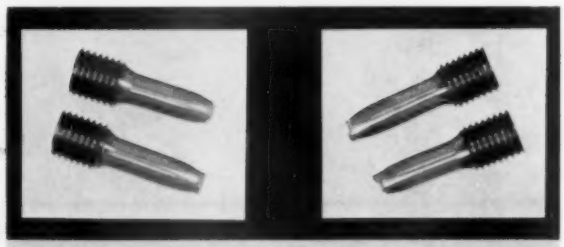
All of the wires may be described as Ni-moly low-alloy steel wires, and all except wires from heats 1006 and D gave satisfactory impact properties when used with composition "E." Heat 1006 wire was modified with vanadium. Weld metal deposited with this wire did not retain its impact properties after stress relief, apparently because of vanadium carbide precipitation. Metal deposited with heat D wire had poorer impact values than others in the group. This is attributed to high-sulfur content. While sulfur does not seem to have as severe an adverse effect on impact properties as phosphorus, results with the D wire showed that it cannot be allowed to reach what is considered to be a normal level for welding wire if impact properties are to be preserved.

After completion of these tests, a specification was drawn up and a full 16,000 lb commercial size heat of wire was obtained. Writing such a specification presents two major difficulties. One is that a specific wire cannot be obtained, and workable ranges must be applied to all elements used. Depending upon how the values of elements occur in the heat, considerable variation in tensile strength can occur. A second difficulty is the necessity for relaxing the maximum specification on the harmful but always present elements such as phosphorus and sulfur and to a lesser extent silicon. Obtaining the low values desired can make the wire prohibitively expensive. The actual analysis of the large heat of wire obtained is shown in Table 5. This table also shows the chemistry of two multipass welds made with this wire and the chemistry of the quenched and tempered base plate in which the welds were made. The wire chemistry is at the low end of the specification for carbon and manganese and about average for other elements. Phosphorus and sulfur are 2 to 3 times the values obtained in most of the experimental wires but are still low by commercial standards. For purposes of identification, the wire has been called 100 and the two welds AW and SR, indicating their thermal condition as being as-welded (AW) or stress-relieved (SR). The large copper



117,300	UTS*	116,400
99,000	YS*	98,500
16.0	%EL	15.0
43.7	%RA	46.0

Fig. 8—Weld metal tensile properties of multipass welds in as-welded T-1 steel. Composition "E"; 100 wire. (UTS* and YS* are ultimate tensile strength and yield strength, in psi, respectively)



126,700	UTS*	118,000
106,400	YS*	103,000
19.0	%EL	18.0
57.8	%RA	58.5

Fig. 9—Weld metal tensile properties of multipass welds in stress-relieved T-1 steel. Composition "E"; 100 wire. (UTS* and YS* are ultimate tensile strength and yield strength, in psi, respectively)

Table 5—Wire, Plate and Weld Chemistry (%)—Multipass Weld 100 Wire Composition E

	Wire	Base Plate	Weld SR	Weld AW
C	0.11	0.12	0.07	0.09
MN	1.70	0.89	1.00	1.09
P	0.009	0.01	0.013	0.013
S	0.008	0.02	0.011	0.014
Si	0.11	0.29	0.41	0.40
MO	0.57	0.48	0.54	0.52
CR	0.36	0.56	0.40	0.41
V	0.01	0.04	0.02	0.03
NI	2.60	0.76	2.23	1.93
AL	0.009	0.04	0.02	0.02
CU	0.07	0.24	0.32	0.11

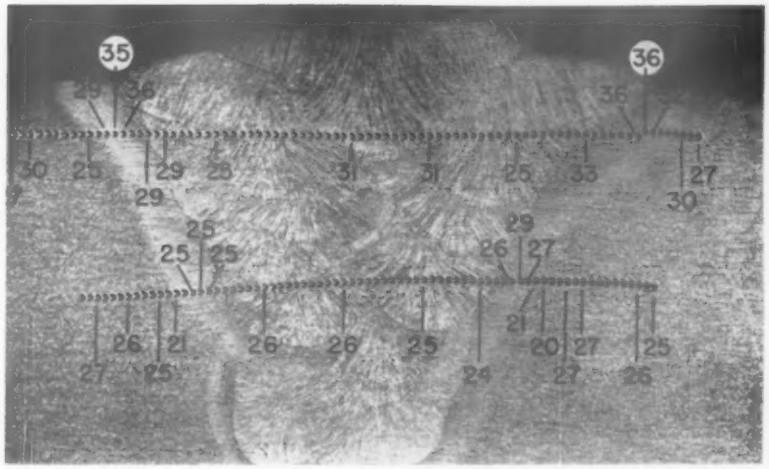


Fig. 10—Cross section of stress-relieved weld. Rockwell "C" hardness from 30 N. × 2

variation in the deposit is apparently due to variations in the coating of the wire since the coil used was one of the first drawn and not up to production standard.

The Charpy "V" impact envelope is shown for the SR weld in Fig. 6. It should be noted that the values are in all cases above the guaranteed values of the steel. Actually these values are approximately 25 ft-lb at −50° F with the transition area around −70° F. Room temperature values are approximately 35 ft-lb. The spread shown at −50° F was obtained using four specimens, two which were stress-relieved for one hour as part of the plate and two which were given an additional 2 hrs of stress relief in an argon-shielded furnace after machining. Two Charpy keyhole values were also obtained at −50° F, and these indicated a slight improvement over the "V" notch value.

Similar curves are shown in Fig. 7 for as-deposited weld metal. The curves are similar to those of the SR plate but show less spread and slightly better values. Keyhole Charpy values were relatively higher than "V" notch values at −50° F.

Tensile properties for AW and SR weld metal are shown in Figs. 8 and 9. Yield-strength values are approximately 105,000 psi in the SR weld and about 99,000 psi in the AW weld. These results generally indicated (*a*) that the desired properties could be obtained with materials produced under commercial conditions and (*b*) that only a slight revision in the wire specification would be desirable to assure a consistent 100,000 psi minimum yield strength value should the wire continue to fall near the low end of its specification.

An extensive field application of the 100-type wire with the chemistry obtained in the wire used here showed that in 2.5 in. plate some yield strengths fell 2000 to 3000 psi below the desired 100,000 psi value. The wire specification was then altered to correct this situation.

It is also of interest to note that multipass welds in 1-in. thick HY-80 plate made with composition "E" and 100 wire exhibit nil ductility temperatures of −70° to −100° F in the as-welded condition as determined by the drop-weight test.

A macrosection of one test weld is shown in Fig. 10 where the weld geometry is apparent. The weld was made in 1-in. thick T-1 plate in a 60 deg. "V" opening in 12 passes using 500 amp DCRP at 30 v and 15 ipm travel speed. Hardness values taken on a Rockwell superficial hardness tester are shown on the cross section. Through the center, these values vary from a low of 24 Rc in the weld to a high of 27 Rc in the base place except for the softened area at the edge of the heat-affected zone where Rc values of 20–21 were obtained.

Separate from the welding of the commercial quenched and tempered steels, considerable progress has been made in the welding of the naval structure steel, HY-800. Approval of the use of the new composition with another special low-alloy wire has been obtained for welding plate up to 1.25 in. thick. The materials were qualified in the explosion bulge test. Experiments with heavier plate are in progress.

Additional work is also in progress on A-203 type steels. As a group these are 3.5% nickel steels and require Charpy impact values on the order of 15 ft-lb at − 150° F. Tensile values are considerably less than required for quenched and tempered high-impact steels, being on the order of 65,000–75,000 psi. Attainment of the required impact values appears within reach, but special wires again will be required. The data presented show that the new composition can provide 60 to 70 ft-lb at −100° F in the 75,000 psi tensile range with ordinary wires. However, the values drop off between −100° F and −150° F, and additional study is being given to wire chemistry.

Welding Characteristics

A multipass welding procedure must be used to achieve the impact properties shown by the data. The reheating affect of subsequent passes is necessary to produce welds with fine grain structure which is a prerequisite to good impact strength. Even if this were not true, restricted heat input would be required to protect the properties of the quenched and tempered high strength base metals used. The usual heat input varies from approximately 45,000 to 60,000 joules per in. In terms of practical welding conditions, this means 450–500 amp at 28–30 v and 15–20 ipm travel speed. Wire of $^{5}/_{32}$ in. diam. is optimum for performance in this current range, although wire in diameters as small as $^{1}/_{16}$ in. has been used.

The new welding composition performs best with d-c welding power, either conventional or constant potential, using 12 x 150 mesh size for all downhand work. Fillet welding or welding with a-c requires 48 x D mesh size composition to obtain proper welding performance. A projected development is the use of the new composition for multipower welding. Limitations on heat input in quenched and tempered steels limit wire deposition rate to values below those

obtained using the common normalized steels. Multipower welding offers a method of increasing deposition rate without increaing heat input per lineal inch because it permits higher travel speeds than single-wire welding. Laboratory tests show that Scott multipower welding can be used with the new composition in the 48 x D mesh size, but this technique has not yet been reduced to field practice.

Summary

1. A fused, nonalloy-bearing, calcium silicate submerged-arc welding composition has been developed which has the ability to provide superior impact properties in weld metal.

2. Wires for the high-strength quenched and tempered steels have been developed and are in the process of being reduced to commercial practice.

EUROPEAN WELDING RESEARCH

(*Continued from page 498-s*)

arc welds of 6% Mg-aluminum alloy plate made with wire of the same composition did not occur with a gas cup $^{5}/_{8}$-in. inside diameter if the argon flow was between 25 and 53 cfh. With a gas cup $1^{3}/_{16}$-in. ID the optimum argon flow was 45 to 100 cfh. The wrinkles were oxide films caused by inadequate gas cover.

• Submerged-arc welding of Hadfield manganese steel is performed with a flux containing 20–25% MnO, 30–35% CaO, 20–25% Al_2O_3, 15–20% CaF_2, and less than 0.02% P. A powder-core electrode is used to deposit weld metal containing 1.0 C, 12.5 Mn, 0.09 Si, 0.016 P. To prevent cracks silicon must be below 0.5%, and phosphorus below 0.030%.

• The repeated impact fatigue strength of welds in two steels measured on unnotched cylindrical specimens bore no relation to the notch impact value. For example, overheated coarse grain structure had poor notch impact value, but high repeated impact fatigue strength.

• The electric resistance of projection welds was computed from flat paper models by an electric integrator, and was measured on a large-scale metal model by means of a galvanometer. The ratio of the resistance of the model to that of a cylindrical resistor having the same diameter as that of the projection at contact was 0.65.

• The electroslag welding process with plate electrode $^{1}/_{8}$–$^{3}/_{4}$ in. thick was used to weld sections $4^{3}/_{4}$ x $4^{3}/_{4}$ in. of steel containing 0.09 C, 22 Cr, 38 Ni, 3 W, 1 Ti (cerium treated). The weld had 75% of the strength of base metal.

• The submerged arc hard facing of tractor links to 400 Brinell is described. A mild steel strip was used as electrode with alloyed flux. The deposit contained 0.25 C, 5 Mn, 0.09 Si, 0.60 Al. The deposition of cast iron strips under a submerged-arc flux also was accomplished.

• Flux compositions and welding conditions are given for the gravity-feed magnetic-flux process without shielding gas. Vertical down welding was performed at 180–200 amp with $^{1}/_{16}$ in. mild steel wire.

Avtomaticheskaya Svarka for April 1961 contains the following articles:

• Aging at 390 to 930° F after welding, embrittled weld metal and HAZ of titanium containing 6.3 Mn or 3.8 Mn, 9.7 V, 2.5 Al. Electron microscopy showed omega phase was the cause of brittleness. No omega phase was found in titanium containing 4.1 V, 6.1 Al and the welded joints were not embrittled by aging. The welds were made by the submerged arc process under fluoride flux in $^{1}/_{8}$ to $^{1}/_{4}$ in. plate at 250–450 amp, 32–34 v, 30 ipm with electrodes of the same composition as plate.

• After 1000 hr at 885° F, austenitic ferritic weld metal exhibited lower notch impact value than as-welded. The decrease in toughness was nearly proportional to the ferrite content, which in turn was governed by the chromium content. At 0.06 C, 17.65 Cr, 9.30 Ni, the percentage of ferrite was 2.8% and there was little loss in impact value. At 22.76 Cr, the ferrite content was 21% and the impact value dropped from 13.9mkg/cm^2 as welded to 4.8 after aging.

• Control systems ranging from stiff to flexible for resistance spot and butt welding are compared. An ignitron circuit for stabilizing current in spot welding is explained.

• A study of resistance welded rail showed that a narrow heated zone provided better ductility but more tendency to weld defects than a wide heated zone.

• Electroslag weld metal was refined in structure by application of ultrasonic vibrations transmitted to the mold by a tapered copper or steel bar.

• Means for ultrasonically detecting defects in resistance butt welded bars are described.

• Partial rectification of alternating current was observed in electroslag casting of ingots and also in single phase arc furnaces for making welding flux with a graphite electrode. The d-c component occurs when the arc strikes to the crucible wall rather than through the slag. The d-c component thus is favored by a slag having poor electrical conductivity for example, 70% CaF_2, 30% Al_2O_3. Prevention of rectification is facilitated by accurate centering of the electrodes, shallower depth of slag bath, insulation of crucible from bottom plate, and proper selection of flux.

• Spot welded joints in mild steel $^{1}/_{4}$ and $^{5}/_{16}$ in. thick had good static strength at room temperature and −67° F.

• The Scott-Tarbell procedure for hard surfacing blast furnace bells by the submerged-arc process using Hastelloy, Hascrome, and Stoody wires is described.

• The cladding of mild steel with Nichrome, 80% Ni, 20% Cr was performed by the submerged-arc process with high-fluoride flux. A single nichrome electrode was used at 230–250 amps, 29–31 v, 15 ipm.

• The addition of 1 to 2% chlorine to argon prevented porosity in aluminum weld metal containing 6% Mg.

Observations on Electrode Melting Rates During Submerged-Arc Welding

Generally accepted relationships between melting rate and current are questioned in work carried out to determine the relative deposition characteristics of single arc, submerged-arc welding when using different current types

BY MICHAEL H. ROBINSON

ABSTRACT. The generally accepted relationship between electrode melting rate and the type of welding current used during submerged-arc welding assumes that the highest electrode melting rate is associated with direct current, straight polarity welding, followed by alternating current and direct current, reverse polarity welding. Previous studies, carried out by other investigators, have concluded that the significant factors controlling submerged-arc welding electrode melting rates were current magnitude, electrode extension and electrode diameter.

Data are presented describing a series of single arc, submerged-arc welding tests carried out to check the authenticity of the above relationships. During the tests, basic welding parameters were standardized by selecting optimum values, based on the results of preliminary check welds, and thus affording a clear cut comparison between each current type and electrode melting rates over a wide range of welding current values—from 500 to 1500 amp. Advantage was also taken of test conditions to check arc voltage effects on electrode melting rates and to determine the influence of welding current type and arc voltage on the amount of welding flux composition fused. Two methods of determining electrode melting rates are described and shown to correlate very closely with each other.

Under the conditions established for this study, results show that the generally accepted relationship between melting rate and current type is not valid. It is demonstrated that the order of precedence of current type with relation to electrode melting rate changes with increasing values of welding current and that arc voltage changes at relatively high welding currents can markedly affect the electrode melting rate. Significant variables affecting submerged-arc welding electrode melting rates, in addition to those quantitatively reported in earlier studies, are shown to be welding current type, arc voltage and welding flux composition. Arc voltage is also shown to be the most important variable in determining the amount of welding flux composition used.

An analytical survey of the recorded results, coupled with a review of published literature, is presented leading to derivation of empirical formulas expressing electrode melting rates for each of the three current types; calculated and observed melting rates are shown to be in close agreement. A hypothetical explanation is given to account for the observed differences in electrode melting rates in terms of anode and cathode heating reactions and drop transfer mechanisms across the welding arc for direct current electrode melting rates and jet stream phenomenon occurring during metal transfer across the welding arc for alternating current electrode melting rates.

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Paper presented at AWS 42nd Annual Meeting held in New York, N. Y., during April 17–21, 1961.

Introduction

It is generally accepted that, when using the automatic submerged-arc processes, the highest weld metal deposition rates are obtained using direct current, straight polarity followed in descending order by alternating current and then direct current, reverse polarity. Data obtained during work on previous projects involving submerged-arc welding in the ACF Research and Development Engineering appeared to contradict the general rule. Because of this and the paucity of published information to substantiate the accepted relationship a study was undertaken to establish a more positive definition of d-c, a-c deposition characteristics covering automatic submerged-arc welding processes.

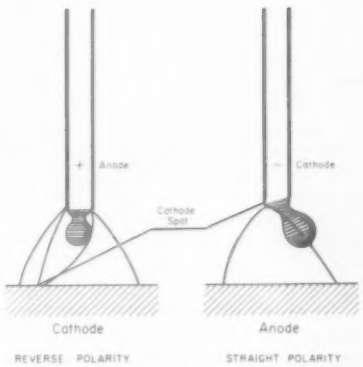


Fig. 1—Effect of polarity on melting of electrode[1]

The objectives of the present study were to determine the relative deposition characteristics of single arc, submerged-arc automatic welding processes when using alternating current and direct current power sources.

Literature Survey

A literature survey covering the field of automatic submerged-arc welding deposition characteristics and related fields preceded the laboratory welding tests.

Virtually no data were found relating directly to the effect of current type on the deposition characteristics of submerged-arc welding with the exception of a paper by Mantel.[1] Mantel suggests that an explanation of the higher electrode melting rates generally associated with direct current, straight polarity can be afforded by considering fundamental char-

acteristics of consumable electrode arcs. Figure 1 illustrates the basic concept of this approach by showing arc configurations for bare wire electrodes in an inert atmosphere at low currents with reverse and straight polarity electrode connections. In each case the arc is uniformly distributed over the anode surfaces and the cathode spot is free to travel at random over the surface available to it. It was asserted that with reverse polarity, (electrode positive), a drop transfers at low current densities when the surface tension of the liquid metal drop is reduced by the increasing temperature to a value below the force due to the electromagnetic field pinch effect. Beyond a certain temperature and current level, boiling occurs at the anode surface and large drops cannot form; the pinch effect is minimized and partial vaporization of the electrode takes place resulting in liquid metal transferring across the arc as small droplets, i.e., spray transfer. Since the end of the electrode, with reverse polarity connection, receives electrons during maintenance of the arc, it was claimed that drops transferring across the arc are uniformly superheated and that the high droplet temperature promoted rapid reaction with welding slags.

With straight polarity (electrode negative) Mantel considered that drop transfer depends upon wandering of the cathode spot. Large drops were said to form because the cathode spot does not remain in one location. The higher the current, the greater the electrode tip surface temperature becomes and the faster the cathode spot wanders. Since the cathode spot spends most of its time at the junction between drop and electrode, larger drop formation and higher electrode melting rates than obtained with reverse polarity connected electrodes were claimed. Drops transferring across the arc were said to be relatively cold as the cathode spot applies much of its heat to the solid electrode itself. Substantiation of the difference in drop size between reverse polarity (small drops) and straight polarity (large drops) submerged-arc welding electrode connections was claimed by Mantel by comparing typical voltage-time traces for each polarity connection. Figure 2 shows such a comparison; it was stated that since no difficulty was experienced in maintaining a smooth arc voltage trace on reverse polarity, whereas it was impossible to obtain a smooth arc voltage trace on straight polarity except at very high current densities, then large drops must be transferring across the arc with straight polarity.

Of particular significance to the present study is the relationship, reported by Mantel and shown in Fig. 3, between submerged-arc welding electrode melting rates and polarity during direct current welding. This relationship indicates that the electrode melting rate increased more rapidly when using straight polarity than with reverse polarity electrode connections. It was further stated that the high electrode melting rate with straight polarity was particularly pronounced with fluxes high in manganese oxide and that increasing acidity of welding fluxes would move the intersection point depicted in Fig. 3 to higher currents, thus inferring that chemical effects due to differing flux compositions have an important bearing on deposition rate characteristics. With alternating current, drop transfer mechanism across the arc was said to be intermediate between direct current straight and reverse polarity and that electrode melting rate during submerged-arc welding was approximately the geometric mean of straight and reverse polarity melting rates.

Work reported by Lesnewich[2] described the melting rates of consumable electrodes in inert atmospheres as being dependent upon anode (reverse polarity) or cathode (straight polarity) reactions and electrical resistance heating. It was concluded that the difference in electrode melting rate between direct current, reverse and straight polarity was partly attributable to the difference in anode and cathode heating. The melting rate using alternating current was claimed to be between those developed using the two types of direct current. It was postulated that since a welding arc can be divided into three zones in terms of voltage drop, i.e., the anode, plasma and cathode potential gradients, the sum of these being the total arc voltage; and since a higher voltage gradient can be demonstrated at the cathode area than the anode area, then more energy must be developed at the cathode thus affording an explanation for the higher melting rate generally associated with straight polarity welding. Test results showed that anode heating was affected by welding current and electrode diameter, cathode heating by welding current, electrode extension and electrode activation and further that electrical resistance heating was proportional to the welding current squared, electrode extension and resistivity and inversely proportional to the electrode cross sectional area.

Wilson, *et al.*,[3] following studies on the effect of I^2R heating on submerged-arc welding electrode melting rate using alternating current, claimed that the total melting rate of an electrode is the sum of the rate due to arc melting and the rate due to I^2R heating (electrical resistance heating) in the length of the electrode extending beyond the welding nozzle tip. The total elec-

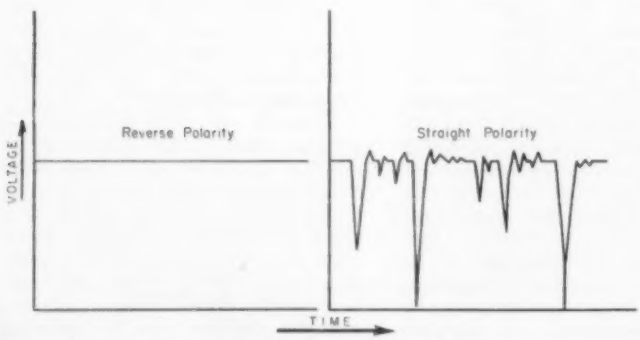


Fig. 2—Voltage-time traces of submerged-arc welding[1]

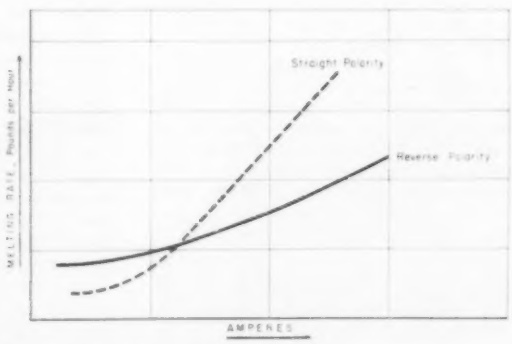


Fig. 3—Effect of current and polarity on electrode melting rate[1]

trode melting rate was given as an exponential function of electrode extension and diameter and welding current as expressed in the following equation:

$$MR = \frac{I}{1000}\left[0.35 + d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.22}\right] \text{ lb/min}$$

where:

MR = melting rate, lb/min.
I = welding current, amp.
L = electrode extension, in.
d = electrode diameter, in.

As will be shown, this expression does not hold true for either alternating current or direct current, straight polarity at high welding current values under the conditions finally established during this project.

Martin[4,5] and co-workers investigated the melting rate characteristics of mild steel welding electrodes and claimed that the electrode melting rate for a given electrode size varied with welding current and was influenced by polarity, arc voltage, arc atmosphere, and changes in weld metal, electrode core wire and base metal chemistry.

Several references are available describing X-ray radiographic studies of the arc zone during submerged-arc welding. Ostapenko[6] reported that welding flux composition influenced the electrode tip to plate distance. Jackson[7] concluded that, for a given welding current and welding flux composition, the electrode tip to plate distance increased linearly with increase in arc voltage and decreased with increase in travel speed or electrode diameter. Independent work by Wilson was cited confirming these results together with data illustrating that changes in welding flux composition would give rise to changes in the electrode tip to plate distance. Tikhodeev[8] records that at a given current level arc voltage increases caused an increase in the electrode tip to plate distance.

The work already referenced above and additional studies by Jackson, *et al.*,[9] record further pertinent conclusions. It was stated that increase in welding current during submerged-arc welding gave rise to an increase in electrode melting rate which could also be influenced by the voltage drop at the electrode. The sum of anode and cathode voltages was claimed to increase as the current increased and to be affected by changes in welding flux composition, arc voltage, travel speed and electrode preheat. Particular attention was given to the effect of different welding variables on the amount of welding flux composition fused during submerged-arc welding; welding current and arc voltage increases both gave rise to an increasing amount of welding flux composition fused; travel speed was considered to have a negligible effect on either welding flux composition fused or electrode melting rate, and it was further reported that normal voltage variations during welding has no significant effect on electrode melting rate. The percentage energy distribution during submerged-arc welding over a wide range of current values (200 to 2000 amp) was shown to vary in the following manner: an approximately constant figure of 15% total energy input required to melt the electrode; a minimum of 3 to 35% ranging up to a maximum of 50% of the total energy required to melt the base material depending upon welding speed and mass of the base material with the balance being expended in melting welding flux composition and losses due to conduction, radiation and convection. Later work by Jackson[10] included check tests at a single welding current level (600 amp) to compare the effects of current type on electrode melting rate and the amount of welding flux composition fused. It was concluded from the results that the type of power source did not influence either the melting rate of the electrode or the consumption of welding flux when using a particular welding flux composition.

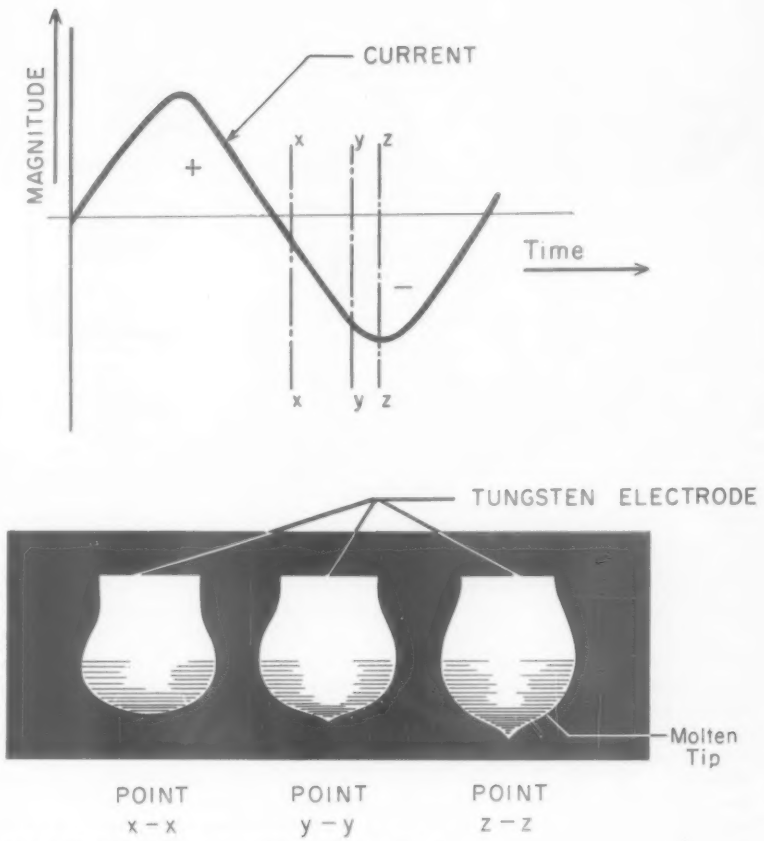


Fig. 4—Effect of alternating current on tungsten tip[3]

Recent work by Needham, *et al.*,[11] has helped to confirm a currently held hypothesis that plasma jet streams play an important part in metal transfer across the welding arc. Plasma jets are reported to be caused by electromagnetic forces acting on the gas in an arc in such a way that the arc acts as a pump setting up gas jets with velocities of the order of 10^4 centimeters per second as compared with 10^2 centimeters per second for the average gas flow rate. One observation claimed to support the presence of plasma jets is illustrated in Fig. 4 which shows diagrammatically the behavior of the molten tip of a tungsten electrode at high alternating currents in an argon atmosphere

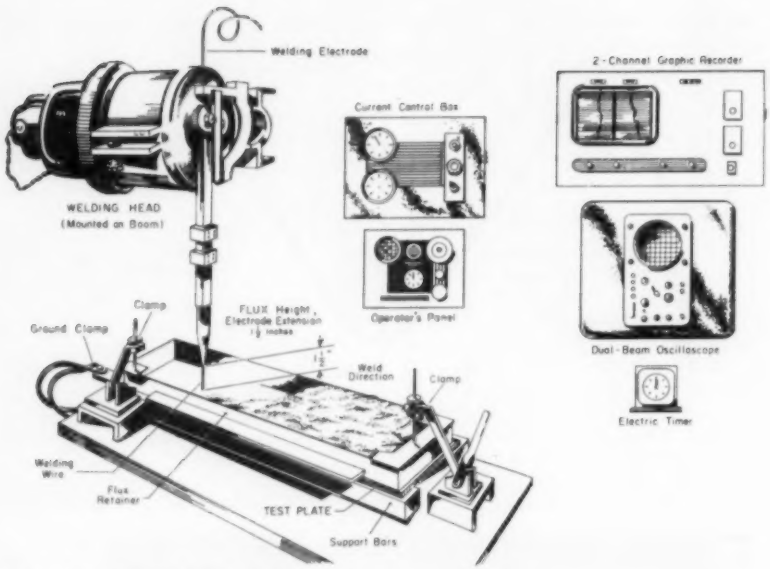


Fig. 5—Disposition of test facilities

during the negative half cycle of current flow. It was stated that, as the current grows and decays during the negative half cycle, a small pimple appears on the fluid electrode tip which grows and collapses in sequence with the current and that this phenomenon was probably associated with the gas flow over the electrode and into the arc. The formation of a plasma jet depends upon a constriction in the arc, i.e., a relatively small electrode diameter in the case of consumable electrode welding, the jet becoming more intense as dissociation and ionization cores develop in the arc causing an increase in current density. It was proposed by Needham that the plasma jet exerts a force on a metal drop as it is forming on the end of the electrode; when this force starts to exceed the restraining force of surface tension, the metal drop begins to pull away from the electrode end and drop acceleration increases as the area of the restricting neck is decreased thus exposing more of the metal drop to the jet. After detachment from the electrode, the metal drop accelerates freely under the action of the jet to a terminal velocity dependent on the force acting on the drop and the distance over which the force acts.

This does not contradict the assertions made by Mantel concerning deposition characteristics. In fact, data presented by Needham help to support the statement by Mantel that droplet size with straight polarity is larger than droplet size with reverse polarity at equivalent current densities. Curves are given showing that droplet velocity increased with increasing current and that these velocities are considerably slower with straight polarity than with reverse polarity. Other observations demonstrated that droplet acceleration decreased as droplet size increased. Therefore, it may be deduced from these relationships that droplet size with straight polarity is considerably larger than droplet size with reverse polarity. Direct observations were reported by Jackson[12] that droplet size using a $^1/_{16}$ in. diam electrode in CO_2 gas resulted in drop diameters ranging from 0.15 to 0.10 in. with straight polarity compared with drop diameters from 0.069 to 0.052 in. with reverse polarity.

General Approach

Consideration of the project objectives coupled with the above review of available literature gave rise to the following list of pertinent variables affecting electrode melting rate which are listed in descending order of relative importance with the exception of current type:

Welding current (magnitude), amp
Electrode extension (I^2R effect), in.
Electrode diameter, in.
Voltage, v
Welding flux composition and size
Electrode chemistry and type
Welding speed, ipm
Base metal chemistry and size

It was considered that by appropriate selection all the listed variables other than current magnitude could be effectively standardized throughout the entire program, thus allowing a clear cut comparison between current magnitude and electrode melting rate for each current type, i.e., direct current, straight and reverse polarity, and alternating current. It was also decided that spot checks would be made to determine the effect of arc voltage changes on electrode melting rate and that the weight of welding flux composition fused would be determined following each test weld.

Material

The materials used in this study were:

1. $^1/_2$ x 4 x 24 in. mild steel test plates per Specification AAR-M-116–55, Grade A. Check analysis: C—0.12, Mn—0.54, Si—0.03, S—0.027, P—0.008 expressed as percentages by weight.

2. 1 x $3^7/_8$ x 23 in. mild steel test plates per Specification AAR-M-116-53, Grade B. Check analysis: C—0.13, Mn—0.39, Si—0.04, S—0.027, P—0.006 expressed as percentages by weight.

3. $^3/_{16}$ in. diam mild steel welding wire. Nominal composition: C—0.13, Mn—1.95, Si—0.03, S—0.03, P—0.03 expressed as percentages by weight.

4. Welding flux composition for general purpose steel welding. Nominal composition: lime magnesia silicate with some alumina and fluospar.

All the materials used were secured from a single heat or lot of material to ensure standardization of materials used throughout the welding tests.

Test Facilities

D-C Tests

A 1200-amp motor generator welding machine was used as a power source to provide welding current for an a-c/d-c submerged-arc welding head having an electronic regulated arc voltage control. A current rheostat was connected in series with the generator field windings to control the welding current output of the generator. The welding head was mounted on the end of a motorized ram-type manipulator which was used to provide a means of controlling the welding speed. Suitable control relays were housed in the welding operator's control panel to synchronize the starting and stopping of welding current with the movement of the manipulator boom and welding head, and also to start and stop an electric timer, thus providing a measure of the actual welding time. Additional instrumentation

comprised of graphic recorders used to provide a continuous and permanent record of all welding currents and arc voltages, and a dual beam cathode ray oscilloscope used to observe current and voltage wave forms either separately or simultaneously during welding.

A-C Tests

The facilities used for the alternating current welding tests were similar except that welding current was provided by two 750-amp transformer-reactor welders connected in parallel. Welding current control in this case was attained through a toggle switch, mounted on the operator's control panel, which was connected to motor drive cores housed in each welding transformer to vary the inductance of each reactor.

Test Procedure

The general disposition of the welding head, instrumentation, test plates and fixturing is illustrated in Fig. 5. After mounting a test plate in position on the support bars, a flux retainer was placed on top of the test plate and locked in position with the hold-down clamps at each end of the flux retainer. The welding head was brought into position, and welding flux composition was placed inside the retainer and smoothed down until level with the sides of the retainer thus maintaining a constant flux blanket depth and width. The test weld was then deposited. Upon completion of the test weld, the test plate was removed, and welding slag was detached and then separated from unused flux composition by means of a close mesh sieve and the test plate and slag stored for subsequent weight determinations. The test plate configuration is shown in Fig. 6. Two test plate thicknesses were used depending on the magnitude of the welding current.

The over-all procedure throughout the test program was as follows:

1. Test plates were sheared to size, weighed and metal stamped with weight and identification number. All weights were recorded.

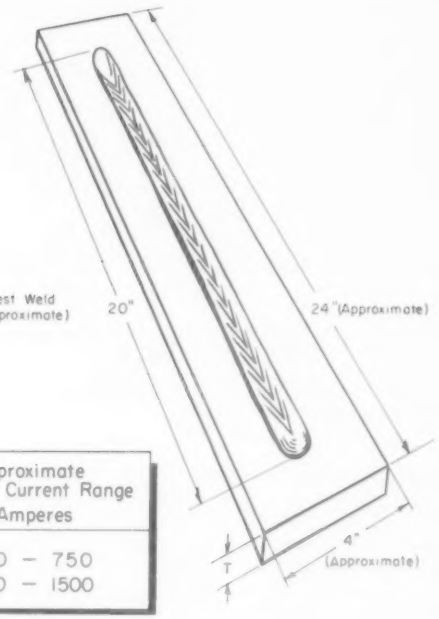
2. Preliminary test welds were made to establish optimum values for all standardized operational variables, i.e., electrode extension, arc voltage, welding speed, flux depth and electrode angle.

3. Actual melting rate tests were carried out by welding three test plates at each current setting using approximately eight steps to cover a current range from 500 to 1500 amp. Electrode consumption for each test weld was checked and recorded by preweld and postweld electrode length measurements; other data recorded for each weld were welding current and arc voltage changes in continuous chart form using graphic recorders, and actual welding time using the electric timer which was synchronized to stop and start with the flow of welding current. Pertinent comments describing each test weld were recorded when appropriate.

4. Checks were made at intervals throughout the range of welding current settings to determine the current and voltage wave forms using the dual beam oscilloscope.

5. All welded test plates were stored removing slag as previously described; after cooling, the test plates were weighed before and after slag removal to determine slag (i.e., welding flux composition fused) and weld metal weights.

The entire procedure was repeated for all three current types: direct current, straight and reverse polarity and alternating current.



Test Plate Thickness Inches	Approximate Welding Current Range Amperes
$\frac{1}{2}$	500 – 750
1	750 – 1500

Fig. 6—Test plate configuration

Results

Table 1 is a tabulation showing the preset and measured data covering all phases of the welding tests; Table 2 shows data derived from the recorded information. These results are described in more detail later but show for each current type that, as the welding current increased, the electrode melting rate and the welding flux composition melting rate both increased. Supplementary check tests were carried out using direct current, straight polarity and alternating current to assess the effect of higher and lower arc voltage settings than the standard setting of 40 v. In each case, above a certain welding current level, increasing arc voltage resulted in a decrease in electrode melting rate and an increase in welding flux composition fused. With decreasing arc voltage the inverse was true—electrode melting rate increased above a certain current level and welding flux composition fused decreased.

Spot checks were made to determine the influence of test plate thickness changes (from $^1/_2$ to 1 in.) for the higher welding current settings. It was concluded that the effect of such changes was negligible. One test weld was repeated after stripping the protective copper coating from the electrode, and no difference was observed due to the removal of the copper coating either during welding or on electrode melting rate.

The information contained in Table 2 was plotted in graphical form to enable easier comparison and more detailed analysis of the electrode melting rates and welding flux composition fused for each current type. Figures 7, 8 and 9 show the electrode melting rate vs. welding current curves for direct current, reverse and straight polarity and alternating current respectively. In each case, melting rate values obtained at a given current setting showed good reproducibility and good correlation between the

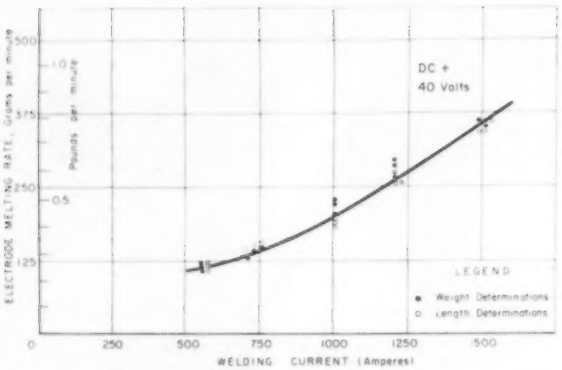


Fig. 7—Total electrode melting rate versus welding current, direct current, reverse polarity

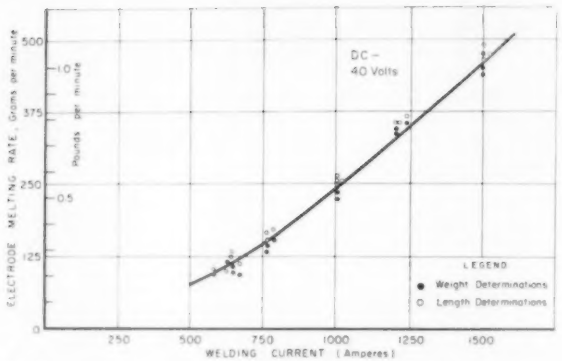


Fig. 8—Total electrode melting rate versus welding current, direct current, straight polarity

two methods used to determine the melting rate values, i.e., weight determinations before and after welding and measurements of electrode length used during welding. As the welding current increased, the electrode melting rate increased, but at different rates, depending upon the current type involved. At relatively low current settings the rate of increase was comparable for all current types; at approximately 750 amp the curve representing direct current, straight polarity started to increase at a faster rate than direct current, reverse polarity. At approximately 1150 amp the alternating current melting rate curve increased at a faster rate than the electrode melting rate when using direct current, straight polarity. For convenience, Fig. 10 shows all three melting rate curves superimposed on the same graph. The theoretical curve due to Wilson[3] and based on work done using alternating current is also shown for comparison. Although comparing well with the melting rate curve for direct current, reverse polarity, it is obvious that under the conditions established for this project the empirical formula suggested by Wilson[3] does not hold true for either direct current, straight polarity or alternating current at relatively high welding current settings.

The effect of increasing welding current on the consumption of welding flux composition, for each of the three current types, was to increase the flux composition melting rate but at a much slower rate than the electrode melting rate. Figure 11 illustrates all three welding flux composition melting rate curves for easy comparison and shows that the highest flux melting rate is associated with alternating current followed by direct current, straight and reverse polarity.

The effect of arc voltage on electrode melting rate when using direct current, straight polarity is well illustrated in Fig. 12 which shows that as the arc voltage decreased the electrode melting rate increased exponentially with increasing welding current. By contrast the effect of voltage on welding flux composition melting rate, as shown in Figs. 13 and 14, indicates that the amount of flux fused increased uniformly as the arc voltage increased during alternating current and direct current straight polarity welding. Reference to Table 2 shows similar voltage effects on electrode melting rate using alternating current; these results have not been shown in graphical form since, in this case, arc voltage changes were not made at the highest welding current settings. As discussed later, the increase in electrode melting rate is attributed primarily to changes in the electrical resistance heating effect and increases in the amount of welding flux fused to the longer arc lengths associated with higher arc voltages thereby exposing a greater area of flux to the high temperatures of the arc column.

Typical welding current and arc voltage traces obtained using graphic recorders for both low and high welding current settings are shown in Fig. 15 covering the three current types. The traces are comparable, and no marked differences can be seen between them except that the alternating current traces at high welding current settings show signs of relative instability when compared with the alternating current traces at low current

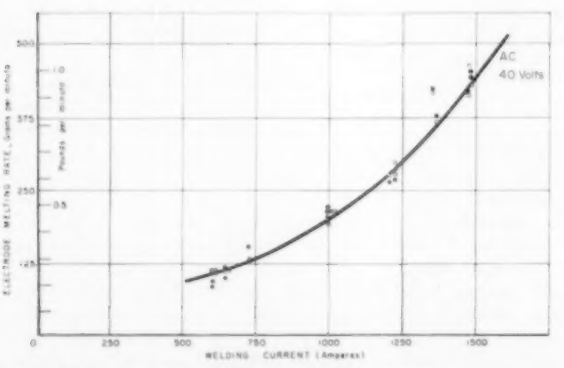


Fig. 9—Total electrode melting rate versus welding current, alternating current

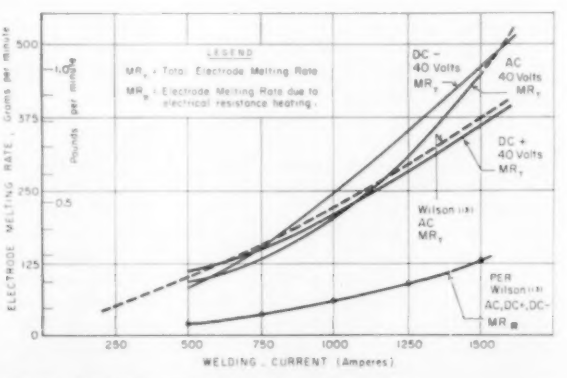


Fig. 10—Electrode melting rates versus welding current, all current types

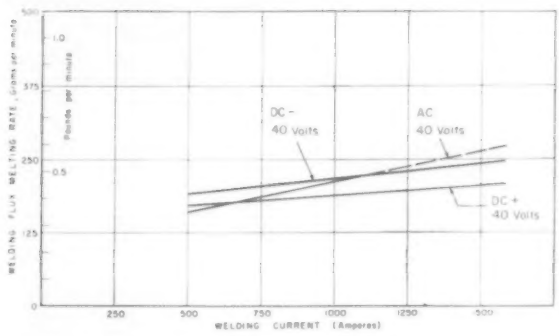


Fig. 11—Welding flux melting rate versus welding current, all current types

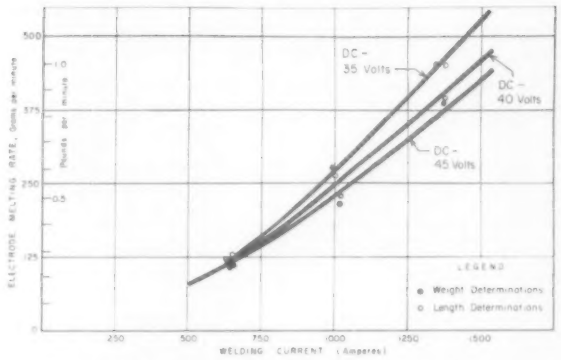


Fig. 12—Effect of arc voltage on electrode melting rate, direct current, straight polarity

settings.

Oscillograph traces of welding current and arc voltage using direct current during the welding tests were difficult to obtain with sufficient sensitivity to allow comparison between direct current, straight and reverse polarity. Current and voltage traces were obtained when using alternating current which permitted wave form types to be studied. Figure 16 is a sketch showing typical welding current and arc voltage wave forms obtained throughout the range of welding current settings used for the alternating current test welds. It is interesting to note that the relatively square arc voltage wave form is characteristic of an open arc discharge; the inference is that throughout the range of currents tested and with the welding flux composition used, an arc-type discharge prevailed rather than a flow of current through a molten bath of conductive slag.

Discussion: Electrode Melting Rate

Effect of Current Type

The reproducibility of the electrode melting rate values obtained during the welding tests and the close correlation obtained between the two different methods used in determining the electrode melting rates are considered to substantiate the results of this work. Additionally, the curves in Fig. 10 representing the effect of welding current on electrode melting rates for direct current straight and reverse polarity show a remarkable similarity to the curves reported by Mantel[1] and illustrated in Fig. 3. This fact alone is considered significant.

Based on the recorded results and the conditions established during the test work, the validity of the formula derived by Wilson[3] is questioned. This formula reflects the effect of three welding variables on electrode melting rate: welding current, electrode extension and electrode diameter. As described by Wilson,[3] the entire expression can be broken down into three basic parts—the effect of I^2R heating on electrode melting rate, the effect of electrode diameter on electrode melting rate, and the effect of arc melting on electrode melting rate.

The first two parts of the formula are logically justified by data reported in the work by Wilson. The effect of arc melting on electrode melting rate, described as a constant of proportionality equal to 0.35 lb per 1000 amp based on the use of alternating current and a specific welding flux composition, represented a terminal melting characteristic and is not considered generally applicable. It is suspected that this factor renders the Wilson formula invalid for the melting rate curves resulting during the present work. The arc melting rate, as shown later during this discussion, is probably dependent upon changes in current type, arc voltage and welding flux composition. Accordingly, a curve representing the first two parts of the Wilson formula is shown in Fig. 10. This curve is expressed by the equation below:

$$MR_R = \frac{I}{1000}\left[d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.22}\right] \text{ lb/min}$$

where:

MR_R = electrode melting rate due to electrical resistance heating, lb/min.

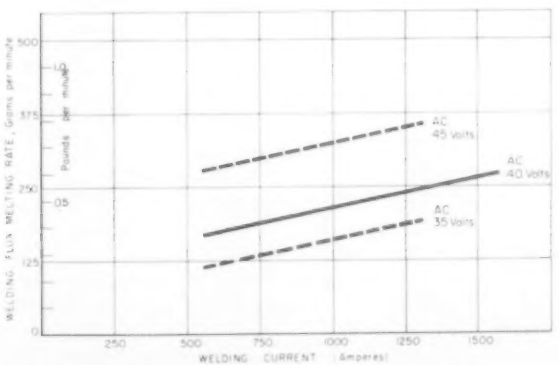


Fig. 13—Effect of arc voltage on welding flux melting rate, alternating current

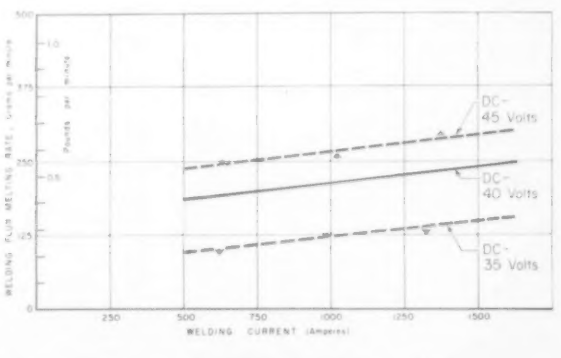


Fig. 14—Effect of arc voltage on welding flux melting rate, direct current, straight polarity

Table 1—Test Settings and Recorded Measurements

Test plate no.	Current type	Current, amp	Voltage, v	Base metal type	Base metal size, in.	Weld time, min	Length of electrode used, in.	Weight, test plate, g	Weight, test plate +weld, +slag, g	Weight, test plate +weld, g
46-2	dc+	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	1.05	58.41	11,380	11,782	11,603
46-3	dc+	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.998	56.06	11,382	11,767	11,592
46-4	dc+	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	1.017	57.44	11,382	11,786	11,590
46-5	dc+	750	40	AAR-M116-55 Gr B	1/2 x 4 x 24	1.000	42.19	6,203	6,530	6,348
46-6	dc+	720	40	AAR-M116-55 Gr B	1/2 x 4 x 24	0.940	37.19	6,186	6,488	6,316
46-7	dc+	700	40	AAR-M116-55 Gr B	1/2 x 4 x 24	0.940	36.78	6,094	6,385	6,214
46-8	dc+	550	40	AAR-M116-55 Gr B	1/2 x 4 x 24	0.958	30.63	6,165	6,416	6,267
46-9	dc+	550	40	AAR-M116-55 Gr B	1/2 x 4 x 24	0.957	30.13	6,039	6,293	6,148
46-10	dc+	550	40	AAR-M116-55 Gr B	1/2 x 4 x 24	0.952	29.53	6,713	6,432	6,278
46-11	dc+	1200	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.948	69.50	11,454	11,879	11,703
46-12	dc+	1200	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.933	69.28	11,348	11,777	11,596
46-13	dc+	1200	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.960	70.72	11,311	11,754	11,568
46-14	dc+	1500	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.965	97.38	11,463	11,997	11,808
46-15	dc+	1500	39	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.973	96.09	11,510	12,054	11,855
46-16	dc+	1480	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.941	91.83	11,444	11,979	11 775
46-17	dc−	1500	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.965	126.31	11,359	12,019	11,788
46-18	dc−	1500	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.961	126.06	11,452	12,139	11,885
46-19	dc−	1500	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.932	124.56	11,406	12,052	11,837
46-20	dc−	1200	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.931	91.06	11,406	11,939	11,717
46-21	dc−	1220	39	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.900	90.94	11,471	11,991	11,784
46-22	dc−	1200	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.940	92.38	11,456	11,966	11,774
46-23	dc−	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.955	69.72	11,418	11,854	11,645
46-24	dc−	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.938	67.94	11,363	11,791	11,591
46-25	dc−	1000	40	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.935	67.91	11,315	11,739	11,541
46-27	dc−	770	40	AAR-M116-55 Gr A	1/2 x 4 x 24	0.960	44.00	6,077	6,439	6,243
46-28	dc−	760	39.5	AAR-M116-55 Gr A	1/2 x 4 x 24	1.000	44.50	6,198	6,550	6,343
46-29	dc−	760	39	AAR-M116-55 Gr A	1/2 x 4 x 24	1.000	42.88	6,243	6,573	6,383
46-30	dc−	760	39	AAR-M116-55 Gr A	1/2 x 4 x 24	0.990	45.16	6,215	6,565	6,360
46-31	dc−	640	40	AAR-M116-55 Gr A	1/2 x 4 x 24	0.920	32.44	6,150	6,441	6,252
46-32	dc−	630	40.5	AAR-M116-55 Gr A	1/2 x 4 x 24	0.966	30.22	6,104	6,411	6,215
46-33	dc−	660	39.5	AAR-M116-55 Gr A	1/2 x 4 x 24	0.950	32.34	6,183	6,457	6,282
46-34	dc−	640	40	AAR-M116-55 Gr A	1/2 x 4 x 24	0.958	33.38	6,202	6,482	6,303
46-35	dc−	640	34	AAR-M116-55 Gr A	1/2 x 4 x 24	0.970	32.59	6,177	6,378	6,287
46-36	dc−	650	45	AAR-M116-55 Gr A	1/2 x 4 x 24	0.960	33.75	6,144	6,485	6,253
46-37	dc−	580	40	AAR-M116-55 Gr A	1/2 x 4 x 24	0.950	26.94	6,058	6,304	6,150
46-38	dc−	1000	35.5	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.938	71.31	11,327	11,700	11,580
46-39	dc−	1020	44	AAR-M116-53 Gr B	1 x 3 7/8 x 23	0.955	62.19	11,327	11,775	11,535

I = welding current, amp
L = electrode diameter, in.

In order to calculate the total electrode melting rate, a further addition to this expression is required that will compensate for the effect of arc melting on electrode melting rate. A general expression for the total electrode melting rate can therefore be written as:

$$MR_T = MR_R + MR_A \text{ lb/min} \quad (1)$$

where:

MR_T = total electrode melting rate, lb/min
MR_R = electrode melting rate due to electrical resistance heating, lb/min
MR_A = electrode melting rate due to arc melting, lb/min

and

$$MR_R = \frac{I}{1000}\left[d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.33}\right] \text{ lb/min} \quad (2)$$

For the conditions established during the test work, MR_T is represented by the curves for each current type in Fig. 10. From the general expression, equation (1), MR_A can be written as:

$$MR_A = MR_T - MR_R$$

Since MR_T and MR_R are represented in graphical form in Fig. 10, the difference in melting rate between MR_T for each current type and MR_R replotted against welding current provides a series of curves showing the electrode melting rate due to arc melting for each current type. Figure 17 shows the curves plotted in linear form, and Fig. 18 shows the curves plotted in log-log form to permit derivation of equations expressing the law of each curve. As might be expected from the previous discussion, an increase in welding current causes an exponential increase in electrode melting rate which varies with current type.

Empirical formulas, based on the curves shown in Fig. 18, have been derived for each of the three current types in terms of welding current versus electrode melting rate due to arc melting. Although restricted to the parameters used during the present study, the formulas serve to emphasize a basic pattern in the observed and derived data and, in addition, provide a sound foundation for qualitative conclusions.

Direct current, reverse polarity

$$MR_{A dc+} = \frac{I^{1.686}}{5.953 \times 10^5} + 0.1331 \text{ lb/min} \quad (3)$$

Direct current, straight polarity

$$MR_{A dc-} = \frac{I^{1.513}}{8.722 \times 10^4} \text{ lb/min} \quad (4)$$

Alternating current

$$MR_{A ac} = \frac{I^{2.721}}{7.686 \times 10^8} + 0.1331 \text{ lb/min} \quad (5)$$

where

$MR_{A dc+}$, $MR_{A dc-}$, $MR_{A ac}$ = MR_A lb/min

and

MR_A = electrode melting rate due to arc melting for each current type
I = welding current, amp

Table 1 (Continued)

Test plate no.	Current type	Current, amp	Voltage, v	Base metal type	Base metal size, in.	Weld time, min	Length of electrode used, in.	Weight, test plate, g	Weight, test plate +weld, +slag, g	Weight, test plate +weld, g
46-40	dc—	1480	45.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	0.940	114.13			
46-41	dc—	1380	44	AAR-M116-53 Gr B	1 x 3⅞ x 23	0.982	107.88	11,444	12,110	11,826
46-42	dc—	1330	35	AAR-M116-53 Gr B	1 x 3⅞ x 23	0.880	111.75	11,368	11,878	11,764
46-43	dc—	1380	33	AAR-M116-53 Gr B	1 x 3⅞ c 23	1.013	112.50	11,472	12,070	11,970
46-44	ac	1480	38.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	0.800	108.44	11,485	12,100	11,865
46-45	ac	1480	39	AAR-M116-53 Gr B	1 x 3⅞ x 23	0.865	110.38	11,255	11,878	11,635
46-48	ac	1220	40	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.013	83.19	11,328	11,838	11,615
46-49	ac	1210	41	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.030	79 75	11,496	12,035	11,765
46-50	ac	1220	40	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.008	79.19	11,340	11,860	11,608
46-51	ac	1220	45	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.020	89.19	11,335	11,970	11,620
46-52	ac	1200	36.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.070	90.50	11,290	11,793	11,605
46-53	ac	1000	39.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.070	63.13	11,348	11,800	11,557
46-54	ac	1000	39.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.081	68.81	11,434	11,892	11,660
46-55	ac	1000	39.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.115	62.44	11,366	11,817	11,595
46-56	ac	1020	44.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.038	63.00	11,455	12,017	11,676
46-57	ac	1000	36	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.000	65.94	11,275	11,660	11,505
46-58	ac	735	39.5	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.110	39.31	11,494	11,850	11,640
46-59	ac	650	39.5	AAR-M116-55 Gr A	½ x 4 x 24	1.150	36.50	5,982	6,280	6,104
46-60	ac	650	39.5	AAR-M116-55 Gr A	½ x 4 x 24	1.085	35.06	6,158	6,457	6,285
46-61	ac	655	38.5	AAR-M116-55 Gr A	½ x 4 x 24	1.115	35.56	6,229	6,513	6,337
46-62	ac	650	39	AAR-M116-53 Gr B	1 x 3⅞ x 23	1.160	36.88	11,355	11,685	11,500
46-65	ac	655	35.5	AAR-M116-55 Gr B	½ x 4 x 24	1.060	35.75	6,225	6,502	6 348
46-66	ac	1350	39	AAR-M116-53 Gr A	1 x 3⅞ x 23	0.790	92.44	11,330	11,885	11,660
46-67	ac	1370	39	AAR-M116-53 Gr A	1 x 3⅞ x 23	0.975	100.25	11,396	11,975	11,765
46-68	ac	1480	40	AAR-M116-53 Gr A	1 x 3⅞ x 23	0.848	102.38	11,446	12,025	11,815
46-69	ac	1470	40.5	AAR-M116-53 Gr A	1 x 3⅞ x 23	0.920	106.63	11,514	12,085	11,895
46-71	ac	600	40	AAR-M116-55 Gr B	½ x 4 x 24	1.123	33.94	6,185	6,500	6,299
46-73	ac	600	40	AAR-M116-55 Gr B	½ x 4 x 24	1.094	32.19	6,199	6,485	6,307
46-74	ac	600	39.5	AAR-M116-55 Gr B	½ x 4 x 24	1.100	31.88	6,237	6,519	6,338

Welding constants:

Welding speed, 20 ipm
Electrode type, mild steel
Electrode diameter, 3/16 in.
Electrode extension, 1½ in.
Electrode angle, sideways, 90 deg
Electrode angle, backwards, 90 deg
Flux type, general purpose
Flux size, 20XD
Flux depth, 1½ in.

The formulas, within the range of welding currents used, infer that in each case the electrode melting rate due to arc melting increases exponentially with increasing current. The melting rate increases slowly at the lower welding currents until the final order of current type, in terms of increasing melting rate, is direct current, reverse polarity followed by straight polarity and alternating current which finally demonstrates the highest melting rate increase as shown by the final disposition of curves representing the total melting rate in Fig. 10.

The general expression $MR_T = MR_R + MR_A$, can now be written as follows:

for direct current, reverse polarity

$$MR_T = \frac{I}{1000}\left[d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.23}\right] + \left[\frac{I^{1.686}}{5.95 \times 10^5} + 0.1331\right] \text{ lb/min}$$

for direct current, straight polarity

$$MR_T = \frac{I}{1000}\left[d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.23}\right] + \left[\frac{I^{1.513}}{8.722 \times 10^4}\right] \text{lb/min}$$

for alternating current

$$MR_T = \frac{I}{1000}\left[d^2 + 2.08 \times 10^{-7}\left(\frac{IL}{d^2}\right)^{1.23}\right] + \left[\frac{I^{2.721}}{7.686 \times 10^6} + 0.1331\right] \text{ lb/min}$$

A tabular comparison is shown in Table 3 comparing the observed total electrode melting rates with the theoretical rates obtained using the above formulas; good correlation is shown between the two sets of values. Each expression infers that, for a given welding flux composition, the total electrode melting rate increases exponentially in terms of the welding current, electrode extension and electrode diameter as concluded from the complete Wilson formula, reviewed collectively; however, it is apparent that current type emerges as a fourth significant factor, causing differing rates of increase particularly at relatively high welding currents as shown by the second part of each expression.

It can now be speculated whether any other factor, in addition to welding current, would influence the second part of each expression, i.e., the electrode melting rate due to arc melting. Lesnewich[2] has claimed that anode or cathode reactions are both influenced by welding current and that the anode reaction is dependent upon electrode diameter and the cathode reaction upon electrode extension and electrode activation when considering consumable electrode arcs in an inert atmosphere. Jackson[9] claims that voltage drop at the electrode can influence the electrode melting rate during submerged-arc welding and states further that the sum of anode and cathode voltages increased with welding current and was influenced by changes in flux composition, arc voltage, travel speed and electrode preheat. Several welding variables may, therefore, influence the electrode melting rate due to arc melting.

Effect of Arc Voltage

Arc voltage was the only variable, in addition to welding current type and magnitude, deliberately in-

Table 2—Electrode and Welding Flux Melting Rates

Test plate no.	Current type	Current, amp	Voltage, v	By weight—Welding flux fused, g/min	By weight—Electrode melting rate, g/min	By electrode length used, Equivalent electrode melting rate, g/min
46-8	dc+	550	40	155	106	113
46-9	dc+	550	40	155	114	111
46-10	dc+	550	40	162	110	110
47-7	dc+	700	40	182	128	138
46-6	dc+	720	40	183	138	140
46-5	dc+	750	40	182	145	149
46-2	dc+	1000	40	170	212	196
46-3	dc+	1000	40	175	210	198
46-4	dc+	1000	40	193	204	200
46-11	dc+	1200	40	186	262	260
46-12	dc+	1200	40	194	266	264
46-13	dc+	1200	40	194	268	260
46-16	dc+	1480	40	216	352	345
46-14	dc+	1500	40	196	358	358
46-15	dc+	1500	39	204	354	348
46-37	dc−	580	40	162	97	99
46-32	dc−	630	40.5	202	115	110
46-31	dc−	640	40	205	111	124
46-34	dc−	640	40	187	105	120
46-33	dc−	660	39.5	184	104	118.5
46-28	dc−	760	39.5	207	145	157.5
46-29	dc−	760	39	190	140	152
46-27	dc−	770	40	204	152	163
46-23	dc−	1000	40	219	238	258
46-24	dc−	1000	40	213	243	256
46-25	dc−	1000	40	212	242	256
46-20	dc−	1200	40	238	334	347
46-22	dc−	1200	40	204	338	347
46-21	dc−	1220	39	230	348	358
46-17	dc−	1500	40	239	445	460
46-18	dc−	1500	40	264	450	464
46-19	dc−	1500	40	230	462	475
46-35	dc−	640	34	94	113	118.5
46-36	dc−	650	45	242	113	124
46-38	dc−	1000	35.5	128	270	269
46-39	dc−	1020	44	251	216	230
46-41	dc−	1380	44	289	388	389
46-42	dc−	1330	35	129	450	450
46-43	dc−	1380	33	99	491	
46-74	ac	600	39.5	164	92	103
46-73	ac	600	40	163	99	104
46-71	ac	600	40	179	101	106
46-59	ac	650	39.5	153	106	113
46-60	ac	650	39.5	158	117	113
46-58	ac	735	39.5	216	150	126
46-53	ac	1000	39.5	227	200	209
46-54	ac	1000	39.5	214	209	209
46-55	ac	1000	39.5	199	206	198
46-49	ac	1210	41	262	261	274
46-50	ac	1220	40	250	266	278
46-48	ac	1220	40	220	282	290
46-66	ac	1350	39	284	417	414
46-67	ac	1370	39	216	378	364
46-69	ac	1470	40.5	206	415	410
46-68	ac	1480	40	248	435	424
46-45	ac	1480	39	281	440	449
46-51	ac	1220	45	343	279	293
46-52	ac	1200	36.5	176	294	299
46-56	ac	1020	44.5	328	213	214
46-57	ac	1000	36	155	230	234
46-65	ac	655	35.5	145	116	118.5

Table 3—Tabular Comparison of Calculated and Observed Melting Rates

I, amp.	MR_E, g/min	MR_A, g/min	MR_T $MR_E + MR_A$, g/min	MR_T graph, g/min
Direct current, reverse polarity				
500	17	87	104	107
750	34	114	148	142
1000	58	147	205	203
1250	89	188	277	280
1500	127.5	232.5	360	360
Direct current, straight polarity				
500	17	63	80	80
750	34	116	150	150
1000	58	180	238	245
1250	89	254	343	348
1500	127.5	332	460	460
Alternating current				
500	17	73	90	90
750	34	99	133	128
1000	58	146	204	203
1250	89	220	309	301
1500	127.5	319	447	448

troduced during the present study. The effect of arc voltage is interesting, especially in view of the claims by some sources that arc voltage has no significant effect on the electrode melting rate. For both direct current straight polarity and alternating current the test results leave no doubt that at high current levels voltage changes have a pronounced effect in causing a marked increase in electrode melting rates as the arc voltage is lowered. Figure 12 shows this effect when using direct current straight polarity. Jackson,[7] and independent work by Wilson mentioned in the same reference, together with Tikhodeev[8] confirm that as the arc voltage increased, the electrode tip to plate distance also increased. Because of this and in view of the recorded increase in welding flux composition fused with increasing arc voltage, it is concluded that as the effective arc length increases due to higher arc voltages a higher percentage of the total available energy is dissipated in melting welding flux composition, since more flux composition is exposed to the arc column, and in energy losses due to radiation and convection. However, no positive relationship exists between the loss in electrode melting rate and the gain in welding flux composition fused as the arc voltage increases. The loss in electrode melting rate does not persist at the lower welding current values, while the percentage gain in flux composition fused for any given arc voltage increase appears to remain constant throughout the range of welding currents tested. It is assumed, therefore, that the decrease in electrode melt-

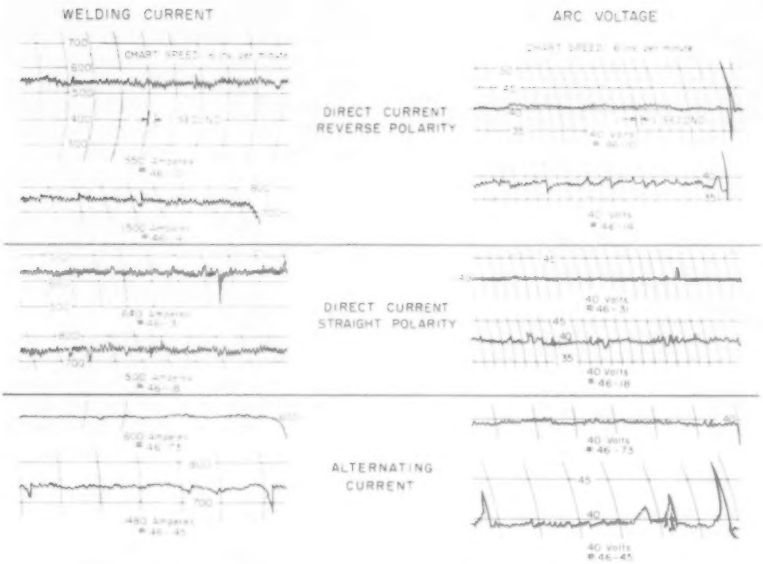


Fig. 15—Typical recorder traces of welding current and arc voltage

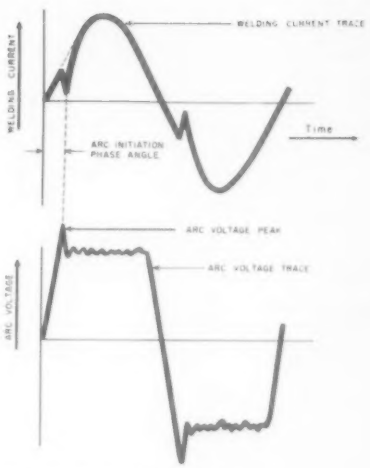


Fig. 16—Typical oscilloscope wave forms of welding current and arc voltage

ing rate with increasing arc voltage is due to the decreasing effect of electrical resistance heating, since the electrode extension becomes smaller with increasing arc length, and that this effect becomes more pronounced at the higher welding current values.

Effect of Welding Flux Composition

Based on data reported in the literature survey, a change in welding flux composition can change the electrode melting rate. Mantel[1] claimed that welding flux composition influenced the electrode melting rate using direct current, straight polarity and also the crossover point of the two direct current melting rate curves shown in Fig. 3. Ostapenko[6] and Wilson, as referenced by Jackson,[7] confirmed that changes in weldng flux composition would influence the electrode tip to plate distance during submerged arc welding.

In view of these observations and the results of the work carried out, the welding variables affecting electrode melting rate during submerged arc welding, in relative order of importance, can be stated as follows:

I = welding current, amp
L = electrode extension, in.
It = welding current type, ac; dc −; dc +
d = electrode diameter, in.
V = arc voltage, v
Ft = welding flux composition

Thus three additional variables, It, V and Ft, all of which can significantly influence electrode melting rate during submerged-arc welding have been shown in addition to the three variables I, L and d, considered by Wilson[3] It and V become influential at relatively high welding currents, i.e., in the current range 750 to 1500 amp.

Metal Transfer During Welding

The precise mechanism of metal transfer during submerged-arc welding is not fully understood. Because of this, a substantiated explanation of the differences in electrode melting rate due to welding current type cannot be given. Based on the information in this report, it is possible, however, that the differences between direct current, straight and reverse polarity electrode melting rates may be due to the differences in metal transfer across the arc proposed by Mantel,[1] described in detail earlier in the report. A second hypothesis, which could either support or replace the statements by Mantel, is the proposal by Lesnewich[2] that anode-cathode reactions cause a proportionate liberation of energy at the electrode, depending upon polarity, which in turn controls the differences in electrode melting rate shown by differing current types. It should be appreciated that the proposals by Mantel and Lesnewich are not necessarily incompatible, since Mantel regarded the mode of metal transfer across the arc as being the most significant factor and Lesnewich considered that the amount of energy developed at the electrode is the more important factor in deciding the differences in electrode melting rate with direct current.

While both explanations appear to be logical when considering direct current, they cannot be applied to cover the behavior of alternating current and its effect on electrode melting rate. Study of the graphic recorder charts shown in Fig. 15, assuming similar instrumentation and welding control circuit responses, indicated that, although for practical purposes, the current and voltage settings at high alternating current values were stable; nevertheless, some instability is apparent when compared with the traces at lower alternating current settings. Typical current and voltage wave forms obtained using the oscilloscope and illustrated in Fig. 16 show an abrupt break in the rising portion of each current half cycle. It is suggested that the interruption becomes more severe as the current magnitude increases as shown in Fig. 19 with the effect of reducing the effective half cycle time period.

Turning now to the mode of metal transfer described by Needham[11] and attributable to the action of plasma jet streams in the arc, it will be seen from Fig. 4 that the formation and action of the plasma jet streams appeared to coincide with the growth and decay of welding current during each half cycle, thus causing a pulsating plasma jet stream action. It is proposed that with alternating current submerged-arc welding plasma jet streams play a predominant role in controlling the mode of metal transfer across the arc and that during the present welding tests jet

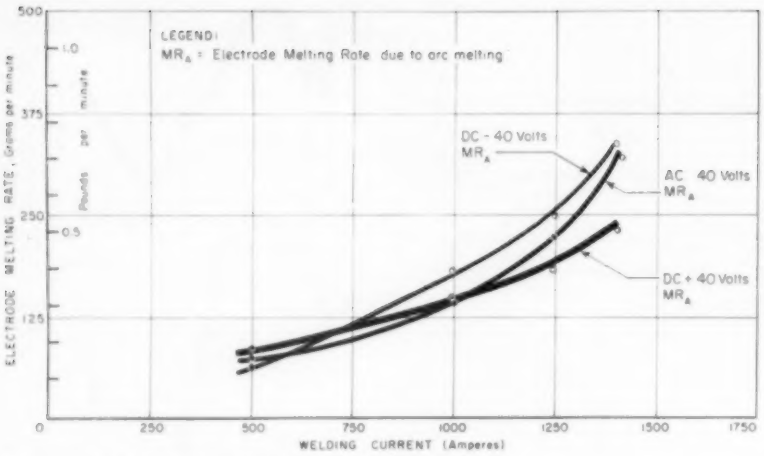


Fig. 17—Electrode melting rates due to arc melting versus welding current, all current types

stream pulses occurred in each complete cycle of welding current at low current levels with intensity of the jet stream action increasing at higher current levels due to the increasing magnitude of welding current and the shorter duration of each effective half cycle, thus causing a correspondingly sharp increase in electrode melting rate.

Welding Flux Consumption Rate

Advantage was taken during the test work to check the effect of current type on the amount of welding flux composition fused. The results inferred that as welding current increased there was a slight gain in the amount of welding flux composition fused, the rate of increase following the same pattern of increases recorded for the electrode melting rate, i.e., the highest rate of increase with alternating current followed by direct current, straight and then reverse polarity. The effect of arc voltage changes on the amount of welding flux composition fused was very striking; in the case of direct current, straight polarity, Fig. 14 shows that at 1000 amp a 5-v increase in arc voltage almost doubled the amount of flux used. This particular effect of increasing arc voltage, causing an increase in welding flux consumption, has been reported by many investigators; the results, however, serve to emphasize a fact that is not always used to advantage in industry.

Practical Implications

Any attempt to apply the findings of this study in the practice of submerged-arc welding must necessarily be qualitative at this stage. In order to gain the fullest advantage, quantitative findings over a wide range of conditions are necessary. This report is felt to provide a good foundation for obtaining such findings: However, it is considered that an awareness of the relationships outlined in this paper can be of practical significance both in the development of submerged-arc welding fluxes and in the practical use of submerged-arc welding. The careful selection of welding current type, welding flux composition and the other important variables listed in this paper for any given welding application can realize advantageous savings by ensuring the maximum utilization of deposited weld metal with minimum welding flux consumption.

Conclusion

It was demonstrated that weld metal deposition rates using the single arc, submerged-arc welding process and a given welding flux composition could be progressively increased, at high welding currents, by changing from direct current, reverse to straight polarity and to alternating current, and by decreasing arc voltage at welding currents in the range of 750 to 1500 amp.

Previously reported and independent work relating increasing welding current, electrode extension and diameter with increasing weld metal deposition was shown to be reasonably valid up to 750 amp but not applicable at higher welding current levels due to the added effects of welding current type, arc voltage and welding flux composition.

Empirical expressions were de-

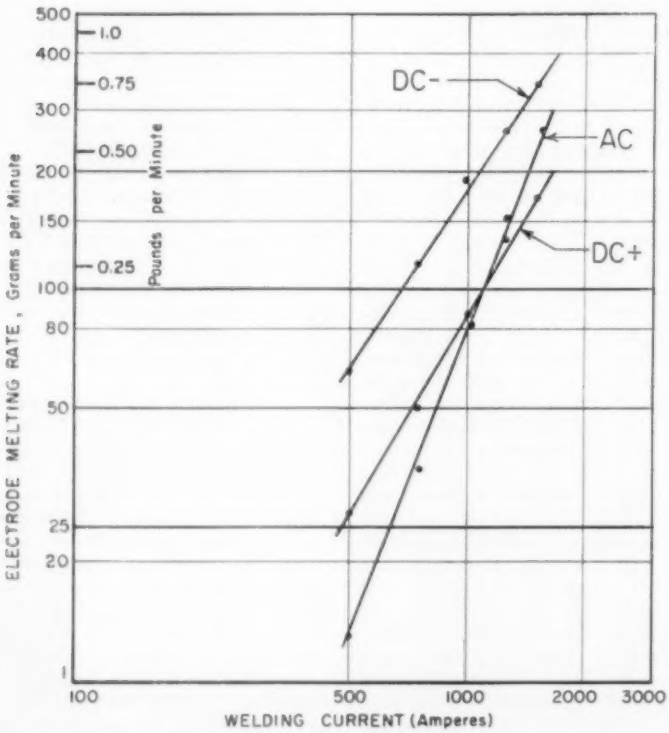


Fig. 18—Electrode melting rate due to arc melting versus welding current, all current types

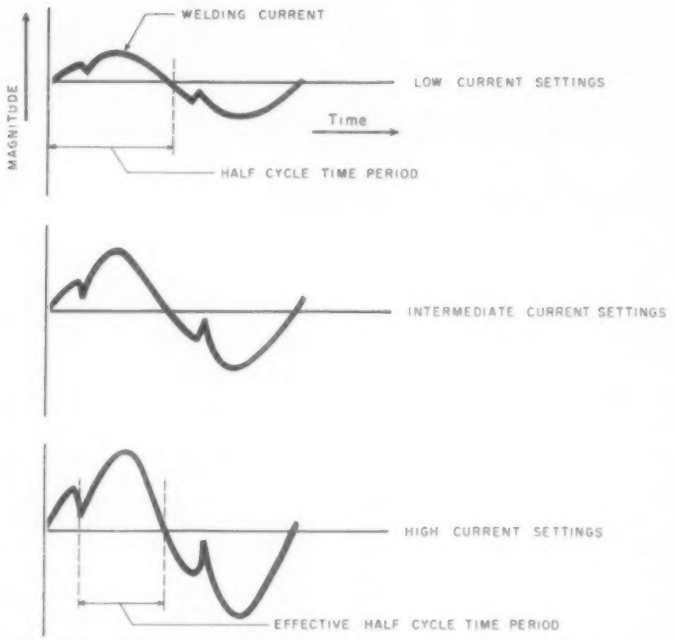


Fig. 19—Probable change in wave form with increasing welding current

veloped relating current type with weld metal deposition for the reported welding conditions. Together with previously reported, independent, data, a general expression was derived showing that the total weld metal deposition was equal to the sum of the deposition rates due to arc melting and electrical resistance heating. Under the established welding conditions, from 500 to 1500 amp, good agreement was obtained between calculated and measured deposition values.

Increasing arc voltage was shown to cause a sharp increase in the amount of welding flux composition fused re-emphasizing a fact that is often not used advantageously in industry.

Acknowledgments

The author wishes to express appreciation to ACF Industries, Incorporated, for permission to publish this work and specifically to James M. Cameron, Welding Supervisor, Research and Development Engineering, American Car and Foundry, for his technical assistance and helpful criticism, and also Alex Basala and Harold Baer, technicians, who performed much of the experimental work.

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Static Brittle Fracture Initiation Without Residual Stresses

Main function of stress relieving is shown to be restoration of ductility

BY C. MYLONAS

Introduction

Residual stresses have been held to be one of the major factors responsible for brittle fracture. On the other hand, they have also been considered as having an insignificant effect on the initiation of fracture. At the root of this disagreement is, of course, the incomplete knowledge of the mechanism of the static initiation of brittle fracture. On some occasions it is even doubtful whether the term "brittle fracture" is used to define one and the same phenomenon. An unambiguous definition may be based on the notion of carrying capacity or limit load of a steel member, i.e., for the present purpose, the load obtained by multiplying the net section by the yield stress. The member cannot be accused of any irregular behavior if it can safely carry its limit load independently of any corners, notches or other cause of stress concentration.* If, however, the member fractures under a load smaller than its carrying capacity, it will be considered as having behaved in a brittle manner. Thus a fracture under a *net average stress* lower than yield stress (or better "flow limit") is defined as a brittle fracture. However, it should not be surmised that the *true* stress at the root of a crack or notch is small. The stress concentration at such discontinuities raises locally the stress to yield intensity while the external loads are still small. As the load increases, the regions surrounding the crack root keep yielding, at first slowly and then with great rapidity as the limit load is approached. However, their stress is of yield intensity or higher (strain hardening).

Stress and Fracture Evaluation Criteria

If the material at highly strained regions can stand the increasing strains of yielding up to the limit load, one can safely say that it has sufficient ductility to avoid brittle fracture. If, however, the material at the notch roots cannot deform as much as needed and starts fracturing before the limit load is reached, one will have what was defined as a brittle fracture. Some particularly useful conclusions can be derived.[1, 2]

1. The net or average stress at fracture (*not* the peak stress) is one possible criterion of the type of fracture. If it is of yield intensity or greater, the fracture is ductile; if it is less than yield intensity, the fracture is brittle.

2. The *true peak* stress at the root of the notch is of yield or raised yield intensity. The fracture starts and advances in a field of high stress. The idea that brittle fracture occurs at low *true* stress is erroneous.

3. The low *average* or *net* stress is not the cause of fracture but only a convenient indication of the plastic strains which the material has sustained before fracture. The true cause is the insufficient ductility at the highly strained areas.

4. The correct assessment of the danger of fracture should be done by a comparison between (*a*) the type and amount of plastic deformation required up to at least the flow limit and (*b*) the ductility of the material during such straining. Such a comparison between required and available ductility can be exactly carried out only if the corresponding problem of plastic strain distribution in the particular member is solved and if the stress-strain law under combined stresses is known up to fracture.

5. Obviously the same material may behave differently in different structures according to the geometry and the requirements of higher or lower plastic deformation for reaching the limit load.

Test Programs

In general, it has been shown by innumerable tests that even the worst structural steel in its virgin condition, with the deepest notches and low temperatures, has sufficient ductility to avoid brittle fracture when subjected to static loading.[1, 2] In all these tests, the limit load was reached and general yielding of the section preceded fracture. The first low average static stress fracture of welded steel was achieved by Weck[3] and Wells.[4] and has been repeated in several variations by other investigators.[5] The test essentially consists in butt welding two large plates with corresponding notches on the welded edges. On subsequent testing in tension in the direction of the weld, a fracture (arrested or complete) was initiated at the original notches. The fracture has been attributed to the strong residual longitudinal tension produced by the shrinking weld.

The first low static net stress fractures of unwelded steel were systematically produced at Brown University by prestraining notched plates in compression in their plane and subsequently testing them in tension (Fig. 1). Fractures of exceedingly brittle nature, whether arrested or complete, were achieved at average net stress down to 10% of yield stress.[2, 6, 7] A further test performed at Brown is the reversed bend test.[8] It consists of bending $^3/_4$ in. thick bars to a small inner radius of curvature and then pulling them open (Fig. 2). Typically brittle fractures at very small loads showing negligible deformation and strains were obtained. Sheet forming tests of a similar nature have been executed in Belgium,[9,10] but with thin sheets and with an indentation at the smallest radius, which may be affecting the results. In the Brown tests, the nominal compressive prestrain by bending is calculated from the minimum radius of curvature. The important aspect of the tests is that they deter-

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*This can obviously be extended by taking as limit a higher load (strain-hardening) corresponding to any arbitrarily defined amount of total extension.

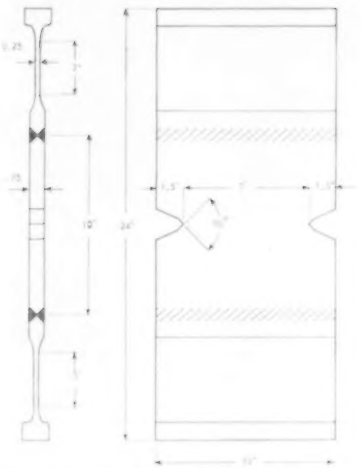

Fig. 1—Notched test plate with plastic hinge pull heads

mine within narrow limits an amount of prestrain below which the material is ductile and above which the material fractures in a brittle way. This limiting prestrain is used to differentiate between steels. The interpretation of the prestrained plate and bent bar tests at Brown University is that the material is damaged by prestraining, i.e., its original ductility is exhausted so much *and in such a direction* that it cannot yield sufficiently *in the manner and direction required* at the root of the notch or at the inner radius of the bent bar, and does not permit the limit load to be reached.

This anisotropy is an important aspect of exhaustion of ductility: Precompression appears to exhaust ductility in subsequent tension in the same direction, but not as much along a perpendicular direction, as has been most clearly demonstrated by the group of the Metallurgy Division of the National Physics Laboratory in England.[11] This anisotropy is extremely strong, and its exact nature and dependence on prestrain are only just being studied. It is clear, however, that the problem of ductility after prestraining is very complicated.

It is true that, besides an exhausted ductility, the notched plates and the bent bars tested at Brown had also high residual tension at the region of fracture initiation. It has been remarked that these residual stresses and not the exhausted ductility are the causes of fracture. However, it is not always realized that residual stresses are the result of mismatch between various parts of a body. They are at most of yield or raised yield intensity and can be wiped out by plastic strains of the order of 0.002 (strain at yield). In effect, residual stresses S of the order of 30 to 60,000 psi would disappear if the stressed material could be deformed at a strain equal to S/E ($E = 3 \times 10^7$ psi) or 0.001 to 0.002, in the suitable direction, because unloading or reduction of stress obeys the elastic stress-strain law with the same Young's modulus as the virgin material. A permanent elongation of this small magnitude will obviously wipe out the residual tension. As is well known, plastic strains of the order of 0.010 are usually evident at the origin of even the most brittle fracture, and they not only wipe out any localized stresses in the same region but may actually transform the stress to the equivalent of compression in the unloaded state. A detailed discussion of the importance of large fields of residual stresses (reaction stresses) and of the probable unimportance of localized stress has already been given.[2] The conclusion is that the importance of residual stresses may be assessed by comparison of the available ductility with that required to wipe out the residual stresses and reach the flow limit.† The tests of Soete[12] show clearly that the fracture can be strongly affected by the size of the region in which residual stresses are stored. The confusion over the role of residual stresses arises from their usual coexistence with prestraining and exhaustion of ductility. Not only the Brown tests but the welded plate tests of Wells and Kennedy and Kihara and Masubuchi contain residual stresses as well as prestrain, the latter arising in the welded plates from differential shrinkage. No clear decision can be reached on the relative importance of these two factors as long as they coexist. Clear differentiation can be done with tests involving each factor separately. If none of them is alone sufficient to produce fracture, it will be concluded that both are necessary for fracture. If, however, in any instance, the one factor alone produces fractures, but not the other then this factor should be accepted as the important one.

Efficacy of Tests for Differentiating Between Influences of Residual Stresses and Embrittlement

Residual stresses are usually produced by some prestraining or differential straining. The influence of each factor can be studied only when the other has been removed by some additional process. But this process must not affect the factor under study. Thus, in most instances, residual stresses are eliminated or reduced either by a high temperature stress relief, or by mechanical stress relief (cold stretching); the resulting improvement in strength is attributed solely to the removal of the residual stresses. However, it is well known that the high temperature of the stress relieving operation (~1200° F) restores ductility to the embrittled steel. Likewise during cold stretching, the notch regions are subjected to additional tensile straining at room temperature. But, as has been found, tensile prestrain does not embrittle steel as much as compressive prestrain, and may even restore some ductility in subsequent tension. Thus, the application of either of these methods of stress relieving affects and changes the ductility of the steel. The steel before and after these operations is not the same, and its properties after stress relieving are not the same as before. Such changes do occur during the stress relief tests of the Well's type of specimen,

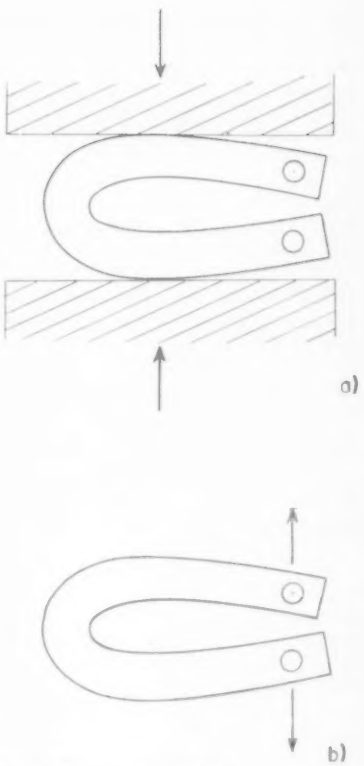

Fig. 2—Reversed bend test

† Note that the limit load of a plastic structure is independent of residual stresses.

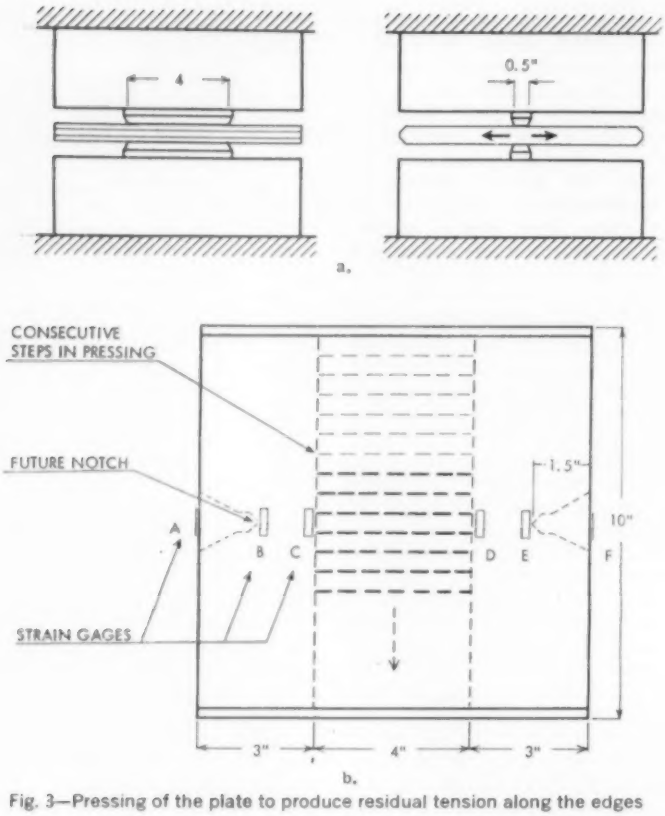

Fig. 3—Pressing of the plate to produce residual tension along the edges

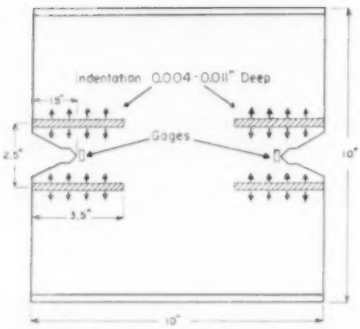

Fig. 4—Lateral pressings for removing the residual tension at the notches of pre-compressed plates

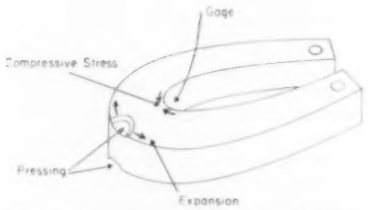

Fig. 5—Exaggerated sketch showing the pressing of bent bars for removing the residual tension at the inner radius

as performed by many investigators. Therefore these results, though excellent in showing the effectiveness of "stress relieving," cannot disclose which one of the two functions of this badly termed operation is responsible for the improvement, namely relief of stress or restoration of ductility.

The proper tests for differentiation between the two factors should either introduce from the very beginning one of the factors alone, or when both exist, remove the one without affecting the other. Thus in the first of the following tests, residual stresses are introduced without any prestrain greater than may be expected in any structure with residual stresses and stress concentration. In the second series of tests involving uniformly compressed bars, the straining is uniform enough to prevent the development of appreciable residual stresses, particularly after turning the bars down to the diameter of the final tension specimens. In the third and fourth tests, residual stresses at first co-exist with exhaustion of ductility. The removal of the residual stresses is achieved by prestraining other parts not participating in the initiation of the fracture. The part which fractures is not given any additional cold work and has the same ductility as before the stress removal. The first two differentiation tests have already been published[2, 11] and are only mentioned briefly and for the sake of completeness of the argument.

1. Tests of Notched Plates Containing Residual Stresses of Yield Intensity But No Prestrain.[2] The residual stresses of yield intensity were produced around the notch roots by the permanent extension (by stepwise pressing) of the middle third of the plate (Fig. 3). No fracture or the slightest arrested crack was observed up to approximately the limit load.

2. Tests of Uniformly Compressed Bars Without Residual Stresses.[13] Since the bars were not notched and the prestrain was uniform, they were free of residual stresses. After prestraining and aging, the bars were tested in tension. Those prestrained by 40 to 45% exhibited a typically brittle behavior and fractured at very small uniform strains down to 0.02. The stress, of course, was high, but it should be remembered that these bars *were not notched.* The measured stress corresponds to the true stress at the root of a crack or notch, which is always high. The tests give a measure of the *true ductility* remaining in the material after precompression. This is directly comparable to the ductility of the precompressed material at the notch roots of the precompressed plates.

3. Tests of Precompressed Notched Plates with the Residual Tensile Stresses Removed from the Regions of the Notches. Notched 10 in. sq. plates of E-steel (identical to those with which low net stress fractures were obtained) were subjected to precompression and then were pressed above and below each notch at a distance of 1.1 in. from the root axis and over a length of 3.5 in. as shown in Fig. 4. The permanent change of thickness under the dies was about 0.008 in. Strain gages cemented $\frac{1}{8}$ in. inside the tip of the notch showed permanent compressive strains of the order of -0.0010 to -0.002 corresponding to an addition of 30,000 to 60,000 psi compression in these regions and much more at the very tip of the notches. Thus, any existing residual tension in these regions must have been strongly reduced or completely wiped out or even transformed into compression. The plates were then tested in tension in the standard way. The results are given in

Table 1—10 in. Precompressed Notched Plate Tests after Removal of Residual Tension by Lateral Pressing (Steel E, 3/4 in. thick)

Plate	Avg. face compression 10^{-3} in.	Test temp. °F	Avg. net tension when cracking occurs, % of v. yield (33,000 psi)	Compressive strain, 1/8 in. from notch, 10^{-3}	Indentation, 10^{-3} in.
18 A	24–23	—6	77	...	22–21.5
18 H	43–43	—12	17, 68, 80	1.5–1.6	
18 Y	50–52	—9	Several: 16% to 30%	...	15–14
19 T	48–42	—14	23, 26, 45, 60, 68, 83, 85	1.1–1.1	8–6
19 O	33–30	—13	16, 38, 52, 79, 91	1.1–1.1	9–9
M 1	35–41	—14	14, 46, 55	1.5	8–9
M 2	51–52	—15	14, 23, 26, 46, 54	1.5	9–8
M 3	40–40	—15	55, 61	1.5	8–8
M 4	43–46	—11	10, 28, 39, 44, 58, 62, 75	1.5	8–8

Table 1, except for two trial plates with indentations at different positions or of much greater magnitude.

A comparison with theresults of standard precompressed plate tests[2,7] shows that the plates behaved in the same way whether with or without residual stresses. In all instances a crack was obtained at a net stress equal to a small fraction of the flow limit.

4. Reversed Bend Tests of Bars with the Residual Tensile Stresses Removed. A similar procedure was followed with the bent bars. A permanent indentation of the order of 0.025 in. was produced over a small part of the lateral surfaces close to the extrados (Fig. 5). This caused the material to flow in all directions. The flow and permanent elongation in the hoop direction produced a compression at the intrados which was measured by a strain gage. Compressive strains of −0.001 to −0.0016 were produced, equivalent to a reduction of any residual tension in this region by 30,000 to 50,000 psi. Six bars of E-Steel and four bars of ABS Class C steel pre-bent to just over the exhaustion limit[14] were tested, with results as given in Table 2. All ten bars showed early cracks and brittle fractures.

Four more bars having prestrains close to the exhaustion limit were tested (ABSC-5 to 8). If the residual stresses had had a significant role in the fracture, their removal should clearly bring these bars into the ductile region. Some of the bars were clearly brittle and some were ductile, with a scatter of results similar to those of the standard bent bars at such prestrain. Measurements of the strains during testing were also made in these tests. A typical graph of the load versus the measured strain is given in Fig. 6. Up to loads of about 400 lb., the maximum strain preceding fracture is less than about 0.001. Up to about 2200 lb it does not exceed 0.01. It is estimated that at 3000 lb the maximum strain is of the order of 0.05. The contrast between the brittle and ductile bars is obvious from their shape. The ductile ones open up almost completely under tension, while the brittle open only very little. After having seen these opened bars and the tremendous strains they can sustain without fracture, it is no longer necessary even to discuss the wiping out of any residual stresses, even if they had not been removed by lateral pressing. But even when fracture occurs at smaller strains—say at 0.01—the residual stresses are wiped out at 1/10th of the fracture load. Only when fractures occur at strains close to 0.001 can one say that the residual stresses have some role. However, such highly embrittled steel fractures at a small fraction—say 500 lb—of the load it could carry when ductile. The existence of residual stresses may further reduce the fracture load to zero. This is certainly not a highly significant result. The material is weak anyway, whether with or without residual stresses. But when the material can stand strains of the order of 0.01 or more, as appears to be the case with usual service brittle fractures, the difference of load corresponding to 0.002 strain (as much as may pre-exist because of the residual stresses) is insignificant. Indeed, external loading in the elastic region by 50,000 lb (raised yield equal also to the highest residual tension) produces a strain of just under 0.002. The pre-existence of such a residual tension corresponds to an initial strain of about 0.002. All the measured strains of a bar with residual stresses should be increased by at most 0.002. Thus a measured strain of 0.01 (or 0.02) at the intrados of a bar with residual stresses corresponds to a total strain (initial plus measured

Table 2—Unbending Tests of Bars after Removal of Residual Tension by Lateral Pressing (Room Temperature; Steels E and ABS Class C, 3/4 in. Thick)

Bar	Nominal compressive strain	Approximate exhaustion limit,[14] ±0.02	Additional compressive strain 10^{-3}	Load at cracking, lb	Remarks
E-1	0.60	...	1.30	1000(2.6),[a] 1000, 1135[b]	.....
E-2	0.60	...	1.20	360(1.4),[a] 500, 700, 1000, 1050, 850[b]	1/8 in. crack at 1050 lb
E-3	0.60	0.50–0.55	1.60	200, 800, 1200[b]	1/4 in. crack at 200 lb
E-4	0.61	...	1.10	1325(3.7),[a] 1050[b]	1/8 in. crack at 1325 lb
E-5	0.61	...	~1.20	300, 1100[b]	.....
E-6	0.61	...	1.25	450(2.0),[a] 450, 720, 1000[b]	1/8 in. crack at 720 lb
ABSC-1	0.60	...	1.35	1100(3.7),[a] 1100[b]	1/4 in. crack
2	0.60	...	1.30	850(2.5),[a] 1100, 1200[b]	1/4 in. crack
3	0.60	0.52–0.56	1.65	1300(4.5),[a] 700[b]	1/4 in. crack
4	0.60	...	1.80	1300(3.5),[a] 500[b]	1/2 in. crack
ABSC-5	0.56	...	~1.50	5000[b]	
6	0.56	...	0.70	.....	No fracture at 6800 lb
7	0.56	0.52–0.56	1.25	2200[b]	Very brittle appearance
8	0.56	...	~1.50	4000[b]	Very brittle appearance

[a] Strain measured at inner radius just before the first crack, beyond which strain gage readings are meaningless.
[b] Fracture. Frequently the load drops after a crack and fracture occurs at a lower load.

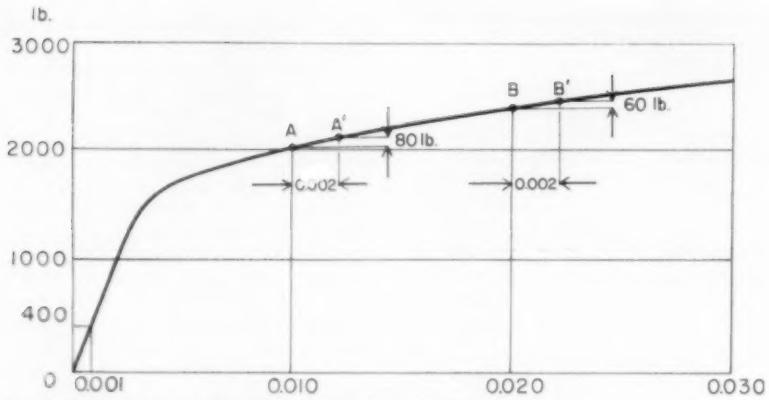

Fig. 6—Load vs. max strain during unbending of bars of ABS class C steel pre-bent to 60% strain

strain) of 0.012 (or 0.022), as shown by points A and A′ and B and B′ in Fig. 6. Thus if an originally stress-free bar would fracture at a strain of 0.012 (or 0.022), the one with the highest residual stresses will fracture at a measured strain of 0.010 (or 0.020). It is seen that the difference between loads at fracture of stress-free and not stress-free bars is very small, about 80 lb at 0.010 strain or about 60 lb at 0.02 strain. In comparison with the applied load of 2000 or 2500 lb this difference is, indeed, insignificant.

Conclusions

It is made clear that tests designed to differentiate between the influences of residual stresses and exhaustion of ductility should not produce any additional prestraining of the notch roots, over and beyond the original prestraining which is being studied. The following conclusions are drawn from the controlled tests designed and performed so as to fulfill this condition and from the original notched plate, compressed bar, and reversed bend bar tests:

1. Precompressed notched plates and prebent bars with exhausted ductility and residual tension at the region of fracture initiation, fracture in a brittle manner.

2. Notched plates with residual stresses but no prestrain do not fracture.

3. Precompressed bars free of initial stresses but with ductility exhausted to about the same degree as in the prebent bars and notched plates, fracture at very small strains in a typically brittle manner.

4. Precompressed notched plates without residual tension but with exhausted ductility fracture in a brittle manner.

5. Prebent bars without residual stresses but with exhausted ductility fracture in a brittle manner.

The answer is clear and unambiguous: The residual stresses did not contribute significantly in the initiation of brittle fracture of precompressed notched plates, of axially precompressed bars, and of bars subjected to reversed bending. Their brittle fracture was due to the exhaustion of ductility in subsequent tension which was produced by compressive prestraining and aging.

These conclusions however, should not be interpreted as arguments leveled against "stress-relieving." On the contrary, they emphasize the need for "stress-relieving" but clarify that its main function is a restoration of ductility and not the relief or reduction of the residual stresses.

It should also be remembered that large fields of residual stress may have an influence on the initiation and more on the propagation of brittle fracture. This discussion has indicated how the comparison between the existing ductility and the ductility required in the suitable direction for the attainment of the limit or higher loads may help calculate the influence of residual stresses and the danger of brittle fracture.

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An Investigation of Corner Connections Loaded in Tension

The results of investigation show that tension type of loading does not limit the application of plastic design of steel structures

BY A. A. TOPRAC

ABSTRACT. A number of straight, bracketed and curved welded corner connections, for portal frames, having a variety of details as to stiffeners, stiffener lengths and geometry, were tested in a manner which produced moments that tended to open the connection legs. This series of tests was carried out on connections tested previously in compression. Also included in this paper are results of two compression tests of prime* specimens.

Although the simulated load is rather infrequent in structures, it increases the possibility of weld fracture at the re-entrant corner which is subjected to tensile stress.

The results reported herein show that tension type of loading does not limit the application of plastic design of steel structures. With proper welding procedures, sound welding and well-designed joints, requirements of strength, stiffness and rotation capacity are assured.

Introduction

A series of tests was carried out to study the structural behavior of welded rigid corner connections or knees.† The results of these compression tests were reported earlier.[1]

This report deals with the results of tension tests primarily performed on the above-mentioned specimens which were previously stressed to the plastic range.[1] Other studies of the same nature—that is, for connections under tension loading—have also been reported.[2] The reader is thus referred to these two papers to avoid unnecessary repetitions.

The forces acting on a knee subjected to compressive loading tend to close its connecting legs as shown in Fig. 1 (a). Under tension loading the connecting legs tend to open as shown in Fig. 1 (b).

Figure 2 (a) illustrates some frames and load lines resulting from two kinds of loading. Common loadings on rigid frames subject the knees to compression—that is, a combination of bending moment and compressive thrust. In Fig. 2 (b), the load line due to a concentrated lateral load on the frame is illustrated. This and the bending moment diagram shown in Fig. 3 indicate that the knee at B is subjected to tension type of loading—that is, the combination of bending moment and tensile forces.

Ordinary wind forces, when combined with gravity live loads, will result in tension loading on the knee only in frames of unusual heights as is shown in Table 1. Although such tension loading is not very frequent, it may be caused by wind forces, earthquakes, blasts and foundation movements; consequently, information regarding the structural behavior of connections subjected to this type of loading is important.

The general requirements imposed on rigid connections have been extensively discussed and reported.[3] The attainment of maximum plastic strength of a structure subjected to special loadings will depend upon proper performance of knees loaded in tension. The requirements as to the behavior of knees under tension are not any different than those for knees subjected to compression loading. These requirements briefly stated are:

1. Strength—the knee must develop at the corner the full plastic moment, M_p, of the rolled shapes connected.
2. Rigidity—the stiffness of the knee should be at least equal to that of an equivalent length of the smaller rolled shape joined.
3. Rotation—the knee must be able to carry the plastic moment through large enough rotations to allow the development of a collapse mechanism.

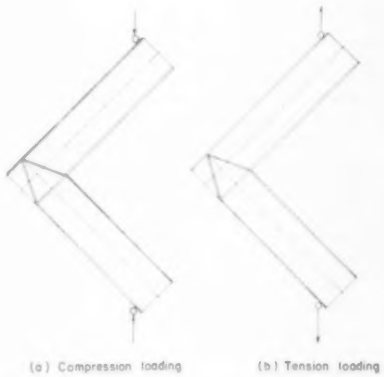

Fig. 1—Loading types

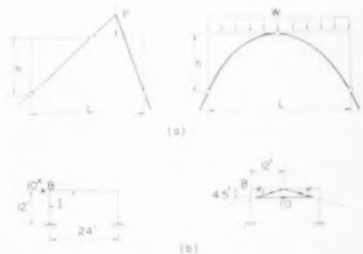

Fig. 2—Load lines of portal frames

Fig. 3—Moment diagram for wind forces

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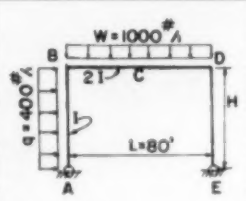
* New specimens; all tension specimens are second hand, meaning they were tested in compression first.

† The terms, connection and knee, are used interchangeably.

Table 1—Combined Moments in Portal Frames

Frame and Loads	H	H/L	M1*	M2**	M2/M1	Type of Load on corner B
	20'	1/4	400	38	0.095	
	40'	1/2	320	149	0.465	
	56'	7/10	276	276	1.00	
	60'	3/4	267	315	1.180	
	80'	1	229	550	2.240	

* Moments due to vertical load in kip-ft.
** Moments due to lateral load in kip-ft.

With the above requirements in mind, the scope of this investigation was as follows:

1. To obtain information on the strength and rigidity of the knees.
2. To compare, where possible, the results with those obtained in the compression tests.[1]

A theoretical analysis of the square-type connections tested has been presented[4] as have further theoretical studies.[5,6] These theoretical studies apply to knees whether loaded in tension or compression. The only difference between the two types of loading is in the delayed local buckling of the compression element when tension is applied, because the compressive bending stresses are reduced by the tensile direct stress due to tension component of the applied load. Consequently, local buckling occurs at higher moments when the connection is subjected to tension loading. Another possible difference is that weld failures are more likely to occur in knees under tension loads.

To facilitate any comparisons with theoretical values, all rolled shapes used in this program were measured to find their actual size. All critical dimensions of the 8 B 13 and 6 I 12.5 were measured with a micrometer and average readings were recorded for all pieces used. Table 2 gives areas, depths and thicknesses of the two shapes. These values are the averages of a large number of measurements. All readings of such dimensions were within 1% of the average in each case.

The same table presents the yield point of the material in these two shapes. These yield points are averages of many coupon tests perfomed at various intervals of time, with the coupons obtained from several pieces of the shapes used in this investigation. Individual coupons vary from the average as much as ±10%. The calculated initial yield and maximum (plastic) moment values shown in Table 2 are based on the average yield point stress of the flange material.

Table 2—Section Properties and Yield Point of Steel for the 6I12.5 and 8 B 13 Rolled Shapes

Section→	6 I 12.5		8 B 13	
item	Handbook	Measured[b]	Handbook	Measured
A[a] in.²	3.61	3.67	3.83	3.80
d in.	6.00	6.02	8.00	8.05
b in.	3.330	3.29	4.00	4.05
t in.	0.359	0.373	0.254	0.245
w in.	0.230	0.221	0.230	0.229
I_x in.⁴	21.8	22.4	39.5	39.5
S in.³	7.3	7.44	9.88	9.81
Z in.³	8.4	8.54	11.4	11.48
f	1.150	1.150	1.152	1.17
σ_{yf} ksi	33.0	44.2[e]	33.0	43.2[e]
σ_{yw} ksi	33.0	56.3[d]	33.0	45.4[f]
M_p in-k	...	378	...	495
M'_p in-k	278	...	376	...
M_y in-k	...	329	...	424
M'_y in-k	241	...	326	...
M_u^c	146	...	198	...

[a] See nomenclature at the end of this report.
[b] These are average values from several readings which were within 1% of the average dimensions shown.
[c] Average of 12 tensile coupons of which 4 are from the plate used as curved flange for connection F. Variations within ±10%.
[d] Average of 7 tensile coupons. Variations within ±10%.
[e] Average of 12 tensile coupons.
[f] Average of 9 tensile coupons.

Test Program

Test Specimens

The knees tested were of Types 1, 7A, 8B, 5A, 4 and 8C.[1,3] Figures 4 and 5 show the various specimens for which results are reported herein. Each knee consisted of two identical rolled shapes joined at right angles. There are two groups of knees. In the first, the rolled shape is an 8 B 13, while in the second it is a 6 I 12.5. In each group there are subgroupings. The specimens with the 8 B 13 are of the square types denoted as R-1, R-2, R-3, and P, and bracketed types denoted as S, T and U; whereas those with the 6 I 12.5 rolled shape of the square types include specimens A, B, C, and in the bracketed type specimen D. Specimen F is a curved knee.

Description of Tests

All specimens were tested in a 400,000 lb screw-type machine. All tension tests were carried out without lateral support. Compression tests, on the other hand, were carried out with the specimens laterally supported as previously described[1] wherein the whole testing procedure is also discussed.

The tension specimens were set with legs at 45 deg with the horizontal. The load was transmitted from the machine through a pair of links at each end of the specimen. Steel pins, 6 in. long, welded on the flange perpendicular to the plane of the web transmitted the load from the plate links which were secured to the heads of the machine by two-inch pins. Figure 6 shows how the tension load was applied by means of links and round bars. Figure 7 is a photograph of the lower pair of links and the moving head of the testing machine.

Rotation data were not obtained. Vertical deflection at or near the load point was measured by means of a deflection gage (Ames dial). The gage was attached to an adjustable rod which spanned the hypotenuse of the triangle formed by the legs of the specimen. The nomenclature used to describe various elements of specimens is given on Fig. 6, which also shows the usual position of the deflection gage. No changes in the average length of the moment arm were measured, and the moments were based on the

original moment arm. However, the error in moment introduced because of this is rather small.

The specimens were whitewashed to facilitate detection of flaking mill scale upon the formation of Luder's lines.

The loads were applied generally in one kip increments in the elastic range. This increment was decreased when the specimens were approaching maximum moment. In the plastic range, readings of deflections were taken only after the balance beam of the loading machine showed that the rate of reduction of load due to creeping had decreased appreciably. A comparison of load reduction due to creeping in the plastic range for readings taken within a few minutes after "apparent" equilibrium of the balance beam, and readings taken 24 hr later, as was necessitated with several specimens, indicates a general load reduction of 2 to 3%, which was not considered excessive for the purpose of these experiments.

It should be noted that specimen S was modified after the original compression test with the addition of a pair of 6 in. long web stiffeners.

Test Results

The results of this investigation are presented below separately for the connections with the 8 B 13 and for the connections with the 6 I 12.5 rolled shapes. In every case the moment-deflection curves for the tension loading are compared with that of the compression loading.

Connections with 8 B 13 Rolled Shape

The following is a description of the behavior of each specimen in this group when loaded in tension. Figure 8 gives the moment-deflection curves for these connections.

Connection U, Type 4. Connection U showed at low loads a definite straight line moment-deflection relationship. The first visible yield lines were observed on the tension flange of the column at a moment of 602 in-kips, followed by yield lines in the web of the beam at 627 in-kips.

At 803 in-kips visible local buck-

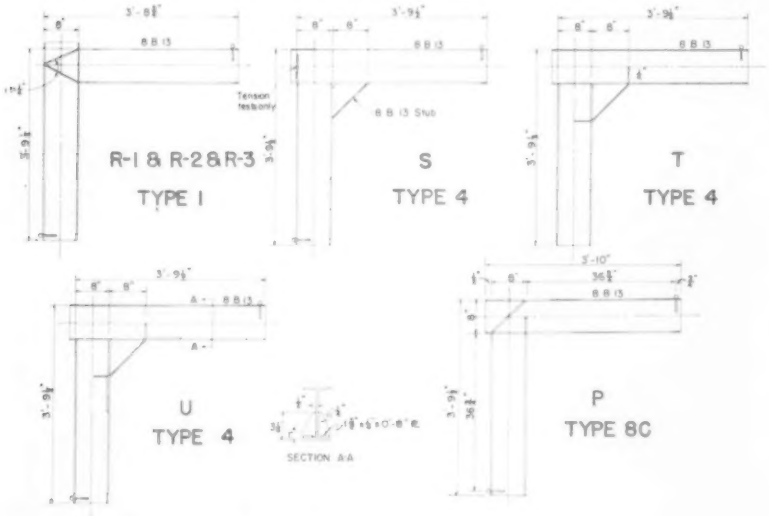


Fig. 4—Connections used in experimental program

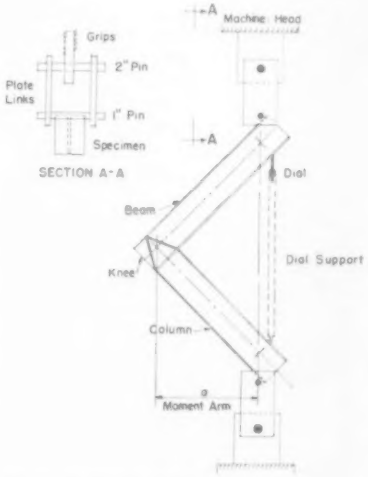


Fig. 6—Diagrammatic sketch of loading and deflection measuring method

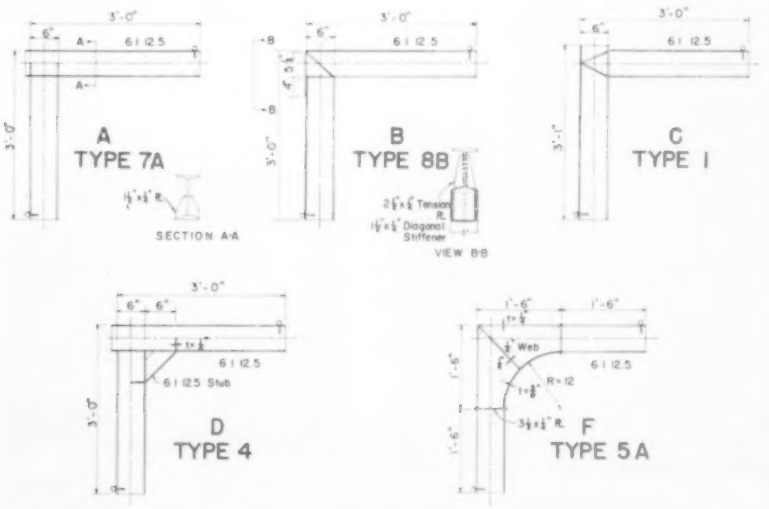


Fig. 5—Connections used in experimental program

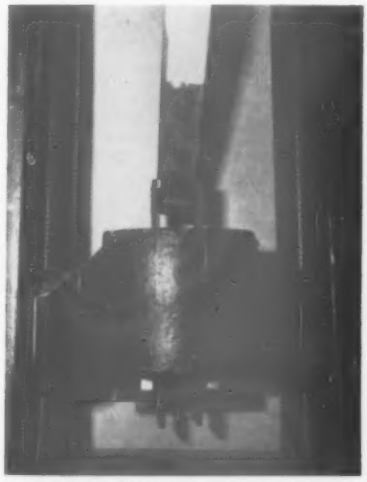


Fig. 7—Part of test set-up showing lower portion of specimen, link plates, bars and moving head of the machine

ling of the compression flange of the column was observed. At 813 in-kips the web of the beam buckled suddenly and the buckling became extensive as the specimen sustained a moment of 813 in-kips. This web vertical buckling is pictured in Fig. 9.

Connection T, Type 4. Yield lines were first observed on the web of the beam at 400 in-kips. At 600 in-kips, yield lines appeared on the compression flange of the column. The beam web buckled at 816 in-kips, the maximum moment. Upon an attempt to increase the load, the beam web buckled excessively resulting in decreasing moment-carrying capacity. Failure was attributed to web buckling.

Connection S, Type 4. It has been mentioned previously that Connection S was modified from the prime connection tested in compression in that a pair of 6-in. web stiffeners were welded to the web of the beam. These stiffeners are visible in Fig. 9. Figure 8 gives the moment-deflection curve for Connection S and compares it to the compression curve.

The first yield lines were observed at 502 in-kips in the web of the column. At 582 in-kips yield lines were observed in the compression flange of the column. These yield lines were followed by others at 602 in-kips on the compression flange and the web of the beam. Local buckling of the beam compression flange occurred at 727 in-kips. Final failure after a maximum moment of 790 in-kips was attributed to the local buckling of the beam compression flange.

Connection R-3, Type 1 and Connection P, Type 8c. Comparison of the tension loading curves to those of compression indicated considerable flexibility of the connections in tension. Connection R-3 exceeded its strength in compression by 75 in-kips—that is, by 11.5%. Connection P was about 20 in-kips or 3.1% stronger in compression than in tension. See Fig. 8.

1. Compression Tests—First yield lines were observed at 283 in-kips for Connection R-3 and 368 in-kips for Connection P. As the loads were increased, new yield lines appeared and the existing ones widened.

The primary failure of both connections was due to local buckling of the compression flange just outside the knee. For Connection R-3 lateral buckling was accelerated due to failure of the lateral braces. This had probably lowered the maximum moment to some extent. The web of knee P showed a considerable buckle as the connection reached failure. Figures 10 and 11 are photographs which show these two prime specimens at the end of the compression test.

2. Tension Tests—The connections in tension showed the first yield lines at 481 in-kips in R-3 and at 424 in-kips in P. Both connections showed an absence of the usual number of yield lines as seen in Figs. 12 and 13.

The weld on one of the loading bars of Connection R-3 cracked and pulled loose before the true maximum moment was reached. The weld between the vertical stiffeners and the flange of the knee of Connection P developed cracks and allowed the web of the knee to carry the high stresses of the re-entrant section. These high stresses eventually caused the web to fracture just above the fillet as shown in Figs. 13 and 14. Inspection of the welds in both connections showed them to be very inferior.

Connection R-2, Type 1. The first visible yield lines appeared on a beam web stiffener at 301 in-kips. These yield lines were followed by others on the compression flange of the column and the beam at 402 and 477 in-kips respectively. At 526 in-kips the lower connecting pin visibly deflected. Finally, at

Table 3. Comparison of Moments

Connection	Type	Rolled Shape	Mode of Failure	Observed Initial Yield Moment in-kips(a)		Col.(5) over Col.(6)	Observed First Yield Line Moment in-kips		Col.(8) over Col.(9)	Observed Max. Moment at Knee in-kips		Col.(11) over Col.(12)	Col.(11) over $M_{p_{(c)}}$	Col.(11) over $M^{\bullet}_{w_{(c)}}$	Obs. Max. Mt. in-k (d) Tension Test	Col. (16) over $M_{p_{(c)}}$	
				Tension Test	Comp. Test		Tension Test	Comp. Test		Tension Test	Comp. Test						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	
U	4	8B13	WB	375	400	0.94	602	492	1.23	813	806	1.01	1.64	4.11	538	1.09	U
T	4	do	WB	670	275	2.44	400	475	0.84	840	673	1.25	1.70	4.24	555	1.12	T
S	4	do	L	303	300	1.01	502	475	1.06	790	620	1.27	1.60	4.00	521	1.05	S
R-3	1	do	*	200	350	0.57	481	283	1.70	735	650	1.13	1.48	3.71	652	1.32	R-3
R-2	1	do	*	200	275	0.73	301	278	1.08	600(b)	508	1.18(b)	1.21	3.04	533(b)	1.08	R 2 Same
R-1	1	do	F	175	280	0.63	300	276	1.09	605	540	1.12	1.22	3.05	537	1.08	R 1 Same
P	8c	do	F	200	425	0.47	424	368	1.15	620	640	0.97	1.25	3.13	550	1.11	P
F	5A	6I12.5	F	360	400	0.90	200	224	0.89	525	642	0.82	1.39	3.60	250	0.66	F
D	4	do	WB	225	450	0.50	325	204	1.60	494	535	0.92	1.31	3.38	340	0.90	D
C	1	do	F	203	280	0.73	203	275	0.74	329	413	0.80	0.87	2.25	295	0.78	C
B	8B	do	F	225	275	0.82	160	122	1.31	310	387	0.80	0.82	2.12	278	0.74	B
A	7A	do	F	180	220	0.82	280	205	1.37	330	324	1.02	0.87	2.26	296	0.78	A

WB = Web buckling
L = Flange buckling
F = Weld failure
* = Loading pin weld failure
(a) = Moment at which deflection curve deviates from straight line.
(b) = Extrapolated
(c) = See nomenclature and Figs. 8 and 17. Table II gives values for M_p and $M^{\bullet}_w$.
(d) = Moment at end of rolled shape (junction knee to shape) when max. load is carried.

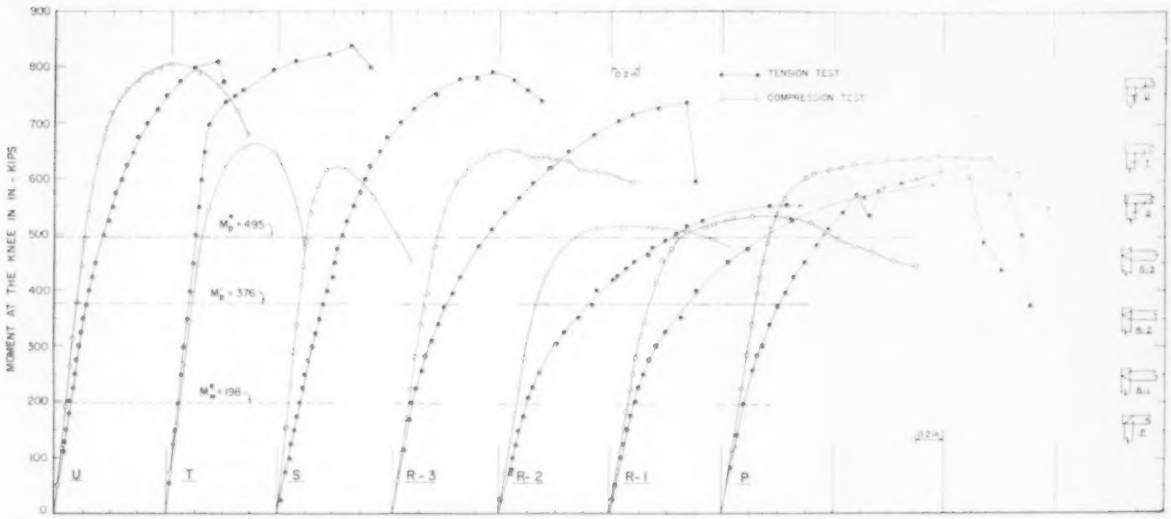


Fig. 8—Moment—deflection curves. Connections with 8 B 13 rolled shape. (See nomenclature)

Fig. 9—Left to right connections S, T and U. Note vertical web buckling of connections T and U

Fig. 10—Compression test of connection R-3. Note yield lines and buckling of the compression flange

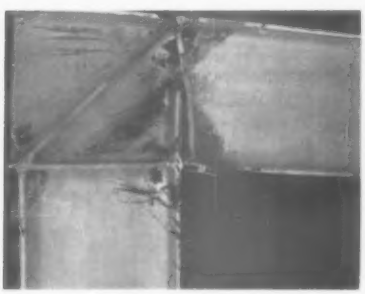


Fig. 11—Compression test connection P. Note yield lines and local buckling of the compression flange

Fig. 12—Tension test of connection R-3. Note yield lines

Fig. 13—Connection P, tension test. Note yield lines and weld failure

Fig. 14—Connection P, tension test. Note yield lines, weld failure, and crack in the beam web

Fig. 15—Connection R-1 at the end of test. Note flange buckling in column compression flange and extensive yielding of web in the same area

Fig. 16—Connection R-1 at the end of test. Note weld failure at re-entrant corner

the knee moment of 555 in-kips or at a direct load of 22,100 lb on the pin, the pin and its weld failed simultaneously and the test was discontinued. There was no apparent structural failure of the specimen. Figure 8 gives the moment-deflection curve for this connection.

Connection R-1, Type 1. The first visible yield lines on R-1 were observed at 300 in-kips on a web stiffener. At 426 and 551 in-kips yield lines developed respectively on the column and beam compression flanges. At 565 in-kips a noticeable crack developed in the re-entrant corner weld on the inside corner of the knee. The compression flange of the column buckled slightly at 577 in-kips. Complete structural failure of the knee weld occurred at the maximum moment of 605 in-kips. Failure of the connection was attributed to the weld failure described. Figure 8 gives the moment-deflection curve for this test. Figures 15 and 16 are close-up photographs of the connection taken after completion of the test. They show, respectively, the flange buckling and weld failure described above.

Connections with 6 I 12.5 Rolled Shape

The following is a description of the behavior of each specimen in this group when loaded in tension. Figure 17 gives the moment-deflection curves for these connections.

Connection D, Type 4. Yield lines were first observed on the compression flange of the column at 325 in-kips. Yield lines on the web of the beam appeared at 386 in-kips and local buckling of the beam web occurred at 494 in-kips, the maximum moment capacity of the connection. At slightly increased loads excessive web buckling was observed and the connection was considered to have failed by web buckling. Figure 18 is a photograph of Connection D upon completion of the tension test. The web buckling and web yield lines are clearly visible in this figure.

Connection C, Type 1. The first yield lines were observed on the tension flange of the column at 203 in-kips. At 244 in-kips yield lines were noticed on the compression flanges of both members.

Visible failure of the inside corner weld was observed at 304 in-kips. The maximum moment resisted by the connection was 329 in-kips. Final failure was attributed to the corner weld failure. Figure 17 gives the moment-deflection curve for Connection C, and Fig. 19 pictures the specimen at the completion of the test. The weld failure is visible in Fig. 19.

Connections A and B. Connections A and B represent, respectively, types 7A and 8B. They are grouped together, because both specimens failed as a result of weld failure on the inside corner of the knee. Figure 19 shows Connections A and B at the completion of the tension test. The moment-deflection curves are given in Fig. 17.

Connection F, Type 5A. Connection F was the only curved connection tested. Its failure, however, was characteristic of Connec-

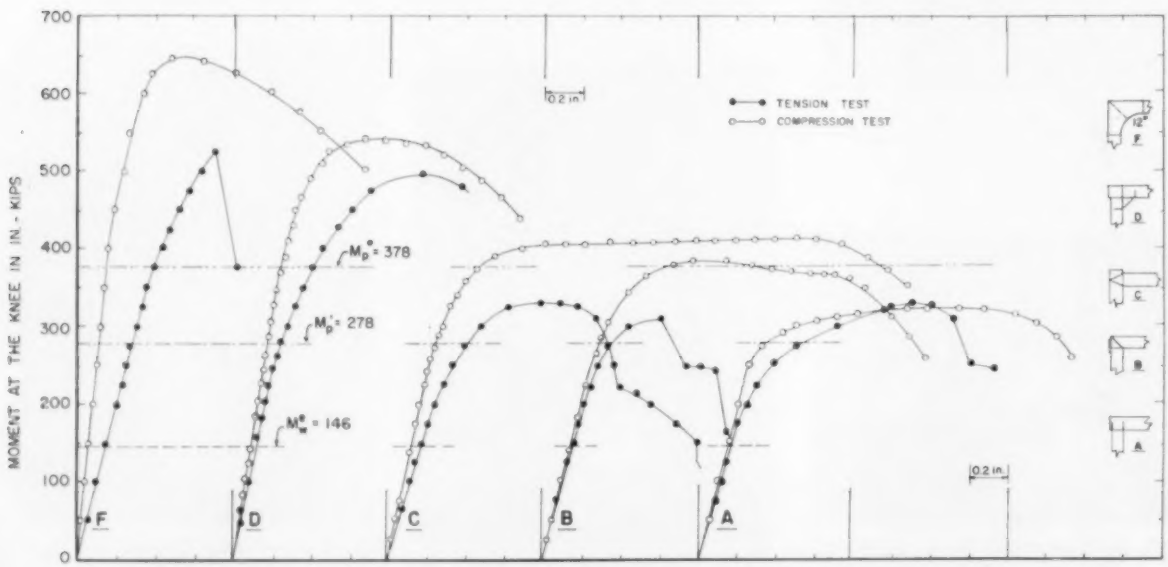


Fig. 17—Moment—deflection curves. Connections with 6 1 12.5 rolled shape (See nomenclature)

tions A and B in that ultimate failure was caused by the cracking of the weld connecting the curved flange to the rolled shape. The first yield lines appeared at 200 in-kips in the compression flange of the column and in the column web.

Visible failure of the weld at the junction of the rolled shape and knee was observed at 406 in-kips, and the crack was extensive at 408 in-kips. Figure 17 gives the moment-deflection curve for this connection. Figure 20 is a picture of Connection F at the completion of the tension test. Test data were not recorded to the extent of weld failure shown. The specimen was purposely opened to the extent pictured to show clearly the nature of the weld failure. Figure 21 is a close-up view of the weld pictured in Fig. 20. At the maximum moment of 525 in-kips, no structural failure of the specimen was noted, other than the weld failure described above.

Fig. 18—Connection D at end of tension test. Note web buckling and yield lines

Fig. 19—Connections A, B and C at the end of test. Note weld failures

Summary and Discussion of Results

In Table 3 a comparison between the observed moments are presented, and the results of the tension tests are compared to those of the compression tests. Further comparisons are to be found in Figs. 8 and 17 where the moment levels of M_p, M'_p and M_w are indicated.

Strength and Rigidity of Connections

Connections with 8 B 13 shape were stronger in tension than in compression. Column 13 of Table 3 indicates that only in one case—that of Connection P—is the ratio of moments less than unity. The same trend can be also noted in Column 17 of the same table where the maximum measured moment at the end of the rolled shape, M_r, is compared to the M_p of the rolled shape using the average yield point.

The same results for connections made with 6 I 12.5 show that these specimens were weaker in tension than in compression and could not develop the plastic hinge value of the section at the end of the rolled shape. This possibly is due to poor welds since four out of five specimens of this group had weld failures as the primary cause for collapse.

Since no rotations were measured for the tension tests discussion of rigidities can only be based on the comparison of moment-deflection curves. It is seen from Figs. 8 and 17 that the connections in tension, with the exception of one, appear to be less rigid than the prime connections in compression. This same behavior has been observed in previous investigations.[2] However, this is so because the tension specimens are second hand. A comparsion between prime specimens in Reference 2, Fig. 7, shows the tension specimen to be stiffer than its twin tested in compression.

Performance of Welds

One of the main differences between the behavior of the connections, when subjected to tension and compression, is that fractures in the welds occurred under tension loading. These fractures were mainly due to stress concentration and they occurred at points of abrupt change of cross section such as the re-entrant corner. However, poor welds were also the cause of many fractures. Column 4 in Table 3 shows which of the connections had such weld failures. It is to be noted that half of the tested specimens collapsed primarily for this reason. With proper inspection and proper welds such failures can be minimized. Possibly straight or square knees should be avoided if tension type of loading is the only load in a rigid connection. This is so because of severe stress concentration at the re-entrant corner.

Columns 13, 14 and 17 in Table 3 show that most of the connections that developed weld fractures compared unfavorably with the compression tests and were not able to develop the plastic hinge value, M_p, of the rolled shape used, not only at the end of the rolled section but also at the knee (Con-

Fig. 20—Connection F at the end of tension test. Note weld failure and yield lines on compression flange of beam.

Fig. 21—Close-up of weld failure in Connection F. Note blow holes and poor weld penetration

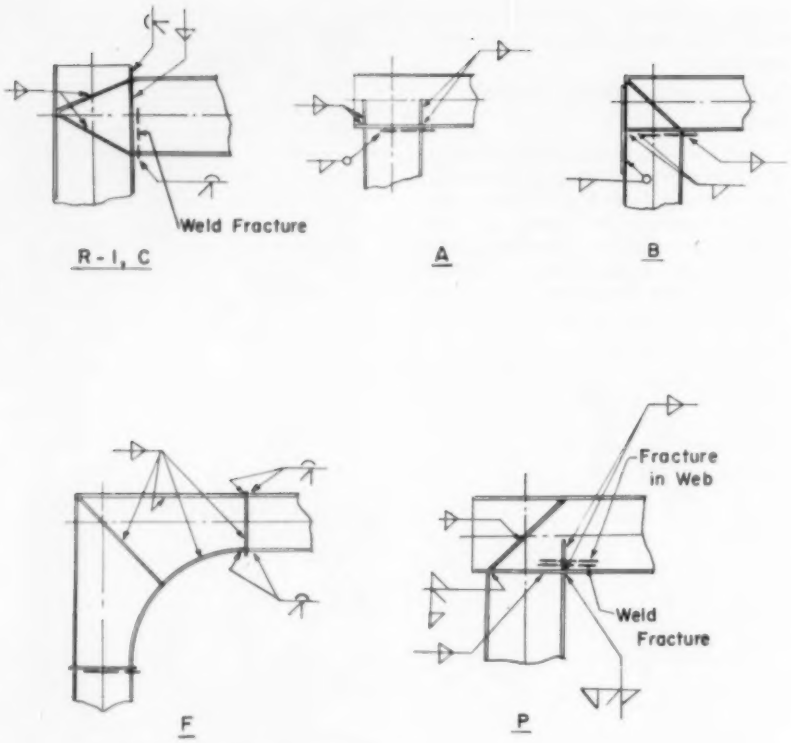


Fig. 22—Location of weld fractures

nections A, B and C). Were these connections fabricated with better welds, it is reasonable to suppose that all would have strength equal or larger than their M_p values, even though at large deflections they might have developed weld fractures. Figure 22 shows the location of welds that cracked.

Conclusions

The following conclusions are based on this investigation and apply to the type of connections tested and the loading used:

1. Except for the connections that developed early weld fractures due to faulty welds, all tests showed higher strengths in tension than in compression.

2. Although most of tension tests showed less rigidity, their stiffness is comparable to that in compression.

3. The weld quality in most specimens was generally poor. This was especially so for connections made of 6 I 12.5 rolled shape.

4. Since the formation of plastic hinges due to tension loading in usual structures is very unlikely, the requirements of strength and rigidity should not be as stringent for tension as they are for compression loading. The results show that welded rigid frame connections properly designed for gravity or usual loads will also be suitable for the tension loadings such frames may be required to carry.

5. With good quality of welding these connection types would be suitable designs even in cases that might require a plastic hinge under tension loading. The results make it obvious that sound welds are necessary when tension loads are to be carried by frame knees.

Acknowledgments

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Nomenclature

A = area of cross section
b = flange width
d = depth of section
F = weld failure
f = shape factor
I = moment of inertia
"L" = local buckling
M = moment
M_p = $\sigma_y Z$, full plastic moment, based on measured values
M'_p = $33Z$, full plastic moment, based on Z from handbook and yield point of ASTM A7 steel
M_y = $\sigma_{yf} S$, based on measured values
M'_y = $33\ S$, based on S from handbook and yield point of ASTM A7 steel
M'_w = $20\ S$, based on S from handbook, and allowable stress of 20 ksi
S = section modules, I/c
t = flange thickness
w = web thickness
WB = web buckling
Z = plastic modulus
σ_{yf} = yield stress level for flange material
σ_{yw} = yield stress level for web material

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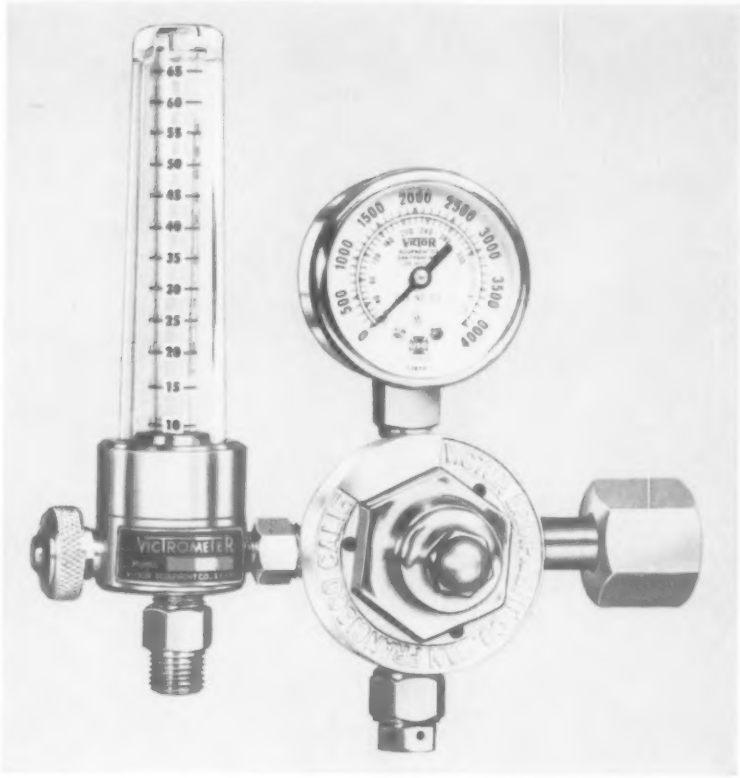

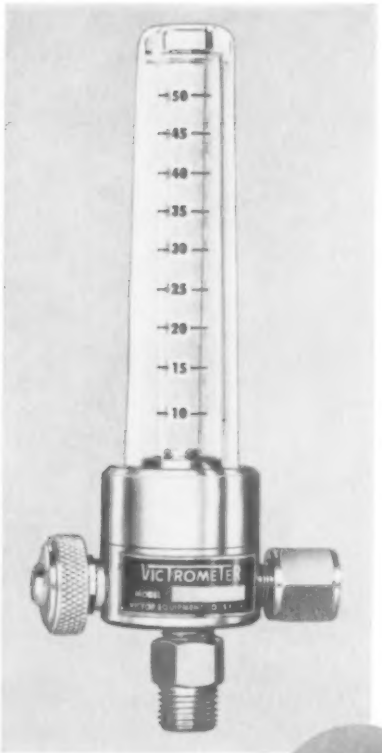

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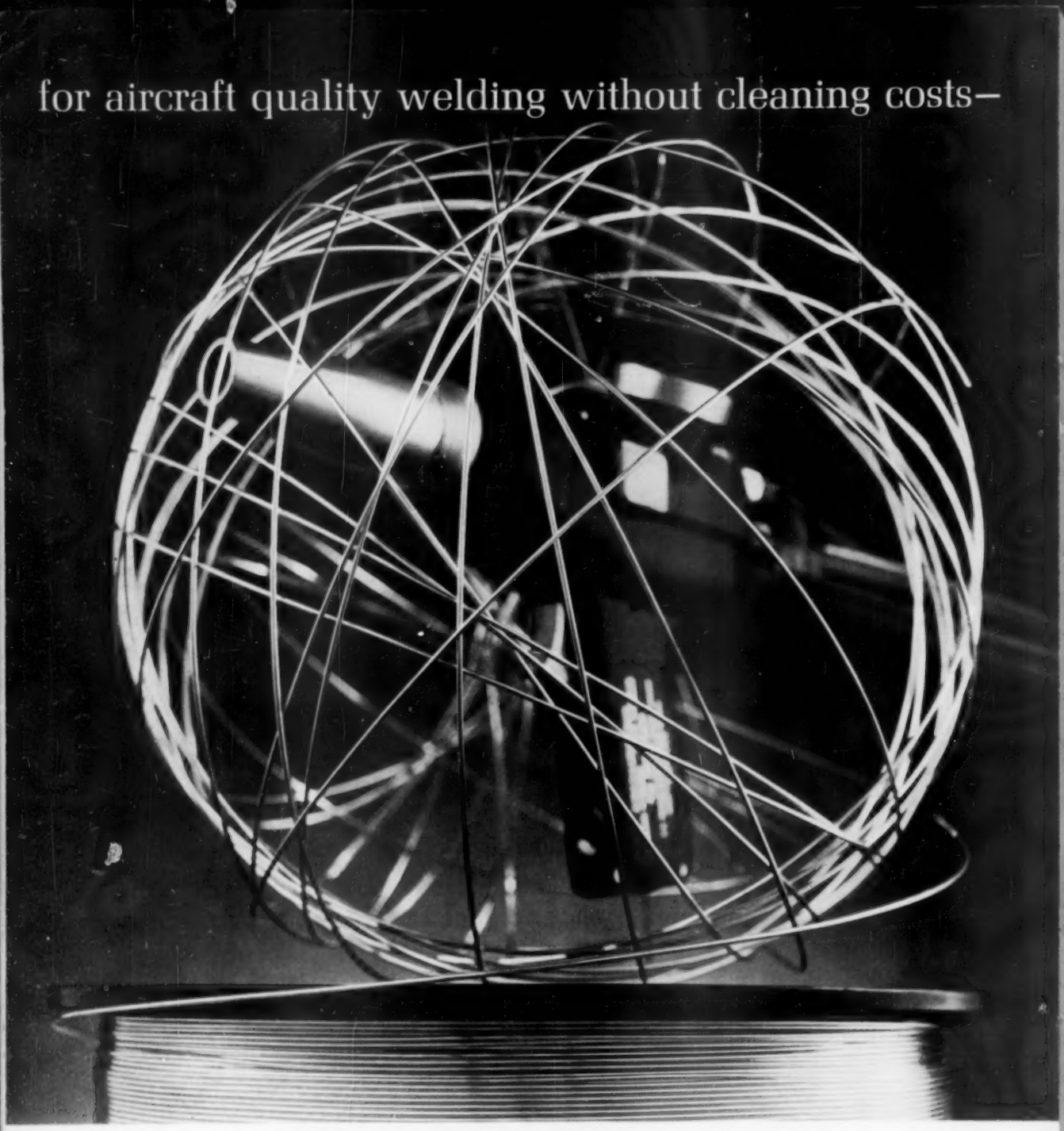

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